A Framework of Assistive Pointers for Low Vision Users

Julie Fraser and Carl Gutwin
Department of Computer Science, University of Saskatchewan
57 Campus Drive
Saskatoon, Saskatchewan S7N 5A9 Canada
+1 306 966 6593
[jdf804, gutwin]@cs.usask.ca

ABSTRACT
Manipulating a mouse pointer is often difficult for the low vision computer user. Working with such a small, mobile screen object is very visually demanding. Although several techniques have been used to address this problem, the design space of assistive pointers has not been fully explored by the current state of the art. This paper proposes a four dimensional framework to fully articulate the design space of assistive pointers for low vision users. The dimensions of the framework describe the key attributes of assistance offered to users by any pointing solution: the perceptual channel that carries the assistance, the stage of targeting supported by the assistance, the relationship between the assistance and the interface, and the degree of availability associated with the assistance.

Keywords
Low vision, partial vision, visual impairment, adaptive technology, mouse pointer, graphical interface

1. INTRODUCTION
The highly graphical nature of WIMP (Windows, Icons, Menus, and Pointers) interfaces can represent a significant barrier for low vision users [12]. Having a reduced level of visual perception means that low vision users are less able to gather visual information. This makes it difficult for them to distinguish fine details like mouse pointers and small iconic screen targets. As a result, it can be difficult for visually impaired users to interact with graphical interfaces using an onscreen pointer. Nevertheless, the visually impaired often attempt to carry out computer interaction using a graphical system pointer [7]. The mouse has become a standard part of the desktop computer systems that most users are familiar with [4], and most operating systems and applications encourage the "point and click" style of interaction [15].

Utilities and aids have been developed to help the visually impaired with pointer manipulation [2]. These aids usually attempt to support the user by improving the visibility of the mouse pointer. Visibility is typically improved by increasing the size or by adjusting the colour of the pointer. Unfortunately, it is often ineffective and problematic to support pointer manipulation in this way. Increasing a pointer's size or changing its colour does not always make the onscreen pointer easier for a visually impaired individual to use. Sometimes these solutions actually make the pointer more difficult for the user to work with. Such simple, visibility-based solutions are limited in their approach, and many other directions exist for the development of new, more effective, assistive pointers.

The particular problem addressed in this paper is that the design space of assistive pointers for low vision users has not been defined or systematically explored. The framework proposed here attempts to map the design space of assistive pointers accordingly. This is an important initial step toward improving the overall usability of onscreen pointers for the visually impaired.

Understanding the solution space will make it possible to classify and organise pointing solutions. The framework will serve as a classification tool in that it presents relevant factors for organising, describing and comparing pointers. These "relevant factors" represent the dimensions of the framework. Using the framework, designers will be able to classify existing solutions, identify overlooked regions of the design space, and design and evaluate new pointers that fill in these gaps. In addition, the framework should also help rehabilitation and technology specialists to better match users to various pointing solutions.

In the first section of this paper, we describe the pertinent aspects of visual impairment, the pointer manipulation problem, and common assistive technology solutions. Next, we present a framework that more fully articulates the design space of assistive pointers for low vision users. This framework includes orienting examples, dimensions of the design space, and the identification of what may be particularly useful or ineffective regions of the design space. Finally, we discuss areas of the design space that have been explored already, the use of the framework to design and evaluate new pointing solutions, future development of the framework, and the importance of matching pointers to user groups.

ASSETS'00, November 13-15, 2000, Arlington, Virginia.

2. BACKGROUND

The following sections describe what it means to have and cope with a visual impairment, outline the pointer manipulation problem in more detail, and summarise the most common assistive technologies that have been proposed as solutions to the pointer problem.

2.1 Low Vision

A person with "low vision" has a profound visual disability, but still retains some useful eyesight. A profound reduction in eyesight can result from two possible sources: reduced visual acuity and restricted field of view.

Reduced visual acuity means having a limited ability to discriminate visual detail [18]. Degree of visual disability is described primarily in terms of visual acuity - the level of sight in the better eye using correction (glasses or contact lenses). Visual acuity in the range of 20/70 to 20/400 constitutes a visual disability. The terms "visually impaired", "partially sighted" and "low vision" are often used interchangeably to describe individuals with a level of vision loss in this range, and will be used as such in this paper.

Restricted field of view means that an individual has a limited range or area that they are able to see [23]. Many of the eye conditions that cause visual disability affect an individual's field of view by causing loss of peripheral vision, loss of central vision, or blind spots [14]. A severely limited field of view can, on its own, be grounds to qualify an individual as having a visual disability. A field of view of twenty degrees or less in the better eye constitutes a visual impairment [23]. Frequently, however, restricted field of view is accompanied by a certain degree of decreased acuity.

In addition to reduced visual acuity and restricted field of view, the visually impaired may be characterised by a number of other attributes [23]. They may have either heightened or reduced sensitivity to certain colours or colour combinations. They may be highly sensitive to bright light, have difficulty adapting to dark or dimly lit environments, or may be unable to control the movement of their eyes. The length of time that an individual has been disabled also plays a role in how effectively they are able to use their remaining vision. Over time, people can learn to better utilise a limited level of eyesight.

2.2 The Pointer Manipulation Problem

WIMP interfaces do not present significant problems for most users. Interacting with familiar screen objects is more natural than remembering the complex textual commands needed to interact with command line interfaces [21]. Furthermore, an onscreen pointer, directed by a mouse, requires minimal effort to operate and is generally well suited to the task of interacting with graphical objects like menus and icons [10].

Unfortunately, these two characteristics of graphical interfaces present problems for many users who have a visual disability. Visually disabled users can have difficulty with the graphical and spatial qualities of GUI environments [12]. One specific problem is that the partially sighted often have trouble using the mouse pointer [7]. This problem can be attributed to both of the primary sources of visual impairment: reduced visual acuity and restricted field of view.

On the computer screen, reduced visual acuity makes the tiny, mobile mouse pointer difficult to find and visually follow as it changes position. The pointer may blend into a non-contrasting background, or may become lost in a clutter of screen objects. Visual detail is also important for precise positioning of the mouse pointer, making it difficult for the low vision user to acquire small screen targets.

On the computer, restricted field of view often makes it impossible for the entire screen to be surveyed as a whole. This means that the mouse pointer can easily end up outside of the user's field of view, and that frequently, it will be impossible for both the mouse pointer and the user's target to both be in view at the same time. This is a problem even for users who do not technically suffer from a restricted field of view. While restricted field of view is, in principle, a medical condition caused by physical limitations on the part of the individual (i.e. damage to the eye or brain), low visual acuity can impose a sort of restricted field of view. When a person must position themselves extremely close to an object in order to see it, the object will fill a large portion of the field of view - thus limiting the number of other objects that can be viewed simultaneously.

These two factors can make mouse manipulation problematic for the low vision user. It is frustrating and inefficient to frequently lose track of the pointer and to have trouble finding it again. It is tedious to carefully scan the screen to locate the pointer when its position is unknown. Focusing on small objects and precise details like the mouse pointer is visually demanding and causes eyestrain. Sitting inches from the computer screen, stretching and hunching to view the pointer and the target objects causes physical strain. These stresses cause fatigue, reduce the length of time that many visually impaired users are able to work at a computer [7], and generally, limit the usability of the onscreen mouse pointer.

2.3 Assistive Technology

Typically, the partially sighted prefer to make optimal use of their residual vision, and so assistive technology for the visually impaired tends to cater to the sense of sight [5]. Devices and aids designed to support the visually impaired usually do so by making objects larger or by improving their visibility [17].

Magnification is the prevailing method of assisting the visually impaired in all types of situations. A broad spectrum of adaptive aids are available for general, real world magnification, as well as for enlarging the contents of the computer screen specifically [16]. Hardware magnification and monitor magnifiers have both been developed and marketed [2], but it is screen magnification software that has become the standard in terms of assistive computer technology for the partially sighted [24].

Screen magnification software provides the user with an onscreen magnifier that works the same as any ordinary magnifying glass. A magnification window tracks the mouse pointer, the typing caret, or the system focus. The window may be the size of the entire computer screen, or it may be smaller and allow parts of the unmagnified desktop to remain visible (Figure 1). The general premise is the same no matter what the case - the magnification window, or zoomed view, is simply an enlarged copy of a portion of the computer screen.

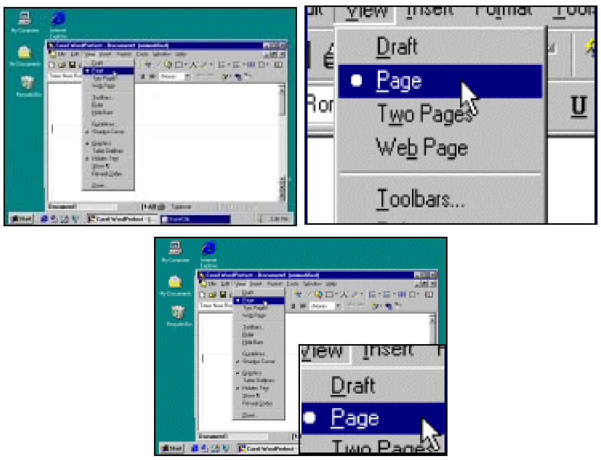

Figure 1 - Screen Magnification Software; unmagnified desktop (top left), zoomed view filling the entire screen (top right), and zoomed view filling one corner of the screen and allowing parts of the unmagnified desktop to remain visible (bottom).

Screen magnification software assists with pointer manipulation in two ways. First, some programs provide limited means of improving pointer visibility. ZoomText Extra [22] allows the user to change the colour and size of their mouse cursor for example. Second, the software effectively tracks and locates the pointer on the fly because the magnification window follows the mouse pointer when the mouse is in use.

While screen magnification software enlarges all screen components in order to make them easier to see, software utilities are also available which will enhance or draw attention to the mouse cursor alone [2]. These utilities are often shareware products, or are bundled with operating systems or mouse drivers. They are not necessarily aimed exclusively at the sight impaired, and include software such as cursor locator and enhancement programs. A cursor enhancement makes the mouse pointer easier to see. It may make the pointer larger, for example. A cursor locator will typically cause the mouse pointer to perform some attention-grabbing action when directed to do so by the user. For example, it may blink when a particular keystroke is executed.

These pointing solutions represent only a small part of the design space of assistive pointers for low vision users. The design space of assistive pointers has not been fully explored by the current state of the art. It is necessary to define and systematically explore this space. It will help us to solve the larger problem of pointer usability for the visually impaired.

3. FRAMEWORK

The following sections describe a proposed framework for the design space of assistive pointers for low vision users. This framework is organised into four dimensions: mode, stage, dependence, and pervasiveness. These four dimensions detail the key attributes of assistance offered to users by any pointing solution.

This framework serves several purposes. It acts as a classification aid by presenting relevant factors by which pointers can be organised. Moreover, by classifying and organising existing solutions, it will be possible to identify overlooked regions of the solution space, and to design and evaluate new pointers that fill in the gaps. As existing solutions to the pointer manipulation problem are often inadequate, it is hoped that the framework will motivate designers and developers to design, implement and evaluate new pointing solutions. Finally, the framework should also help rehabilitation and technology specialists to better match users to various assistive pointers.

The primary focus of this framework is assistance with targeting tasks. Targeting is the act of selecting a screen object. Because all mouse actions begin with a targeting task, targeting is the fundamental component of mouse manipulation. Foley et al. [6] describe the six types of interaction tasks that are suitable for pointing devices. All of the tasks have targeting in common, and require the user to point to the interface element that they wish to act on. If targeting tasks can be made easier for the low vision user, the overall usability of the onscreen mouse pointer will be improved.

3.1 First Dimension - Mode

Mode refers to the perceptual channel (or channels) that are used to provide assistance to the user. Mode may be visual, auditory, tactile, or any combination of the three (Table 1).

Level:	Definition:	Example:
Visual	Information is exaggerated visually.	RollOver on the MSWord Button Bar (Figure 2)
Auditory	Information is exaggerated using sound.	Sound Implementation of Target Mouse [9] (Figure 3 bottom)
Tactile	Information is exaggerated using haptic or force feedback.	Virtual Reality Mouse with Gravity Interface [3] (Figure 4)

Table 1 - Summary and examples of the Mode dimension

Most assistive technology for the visually impaired operates along a visual modality. However, exploiting other modalities can be of benefit to low vision users. It is useful to conceptualise visual disability in terms of bandwidth along the channel of visual perception. The bandwidth of a fully sighted person's visual channel describes the norm. The bandwidth of a blind person's visual channel is negligible. A person with low vision falls in between the two. The partially sighted user suffers from a significantly narrowed channel of visual perception, but is still able to collect a considerable amount of visual information about their environment.

In the real world, when the visual channel of perception is used to assist someone with low vision, visual information along the channel is exaggerated or augmented. Objects may be magnified or their contrast may be improved, for example. This is often accomplished using optical aids like magnifiers, or specialised assistive devices like large print calculators or clocks [16]. Frequently though, the partially sighted are able to compensate for their disability by using other perceptual channels and environmental redundancy to make up for their narrowed channel of visual perception [18].

Essentially, the partially sighted take advantage of the multi-modal nature of the real world. Everyone does this to a certain extent. We use visual perception as the primary means of gathering information, and employ our other senses in a supportive or supplemental capacity [4]. For the visually impaired though, paying close attention to other perceptual channels is of particular value. The richness of experience offered by the real world allows the visually impaired to build up a sufficient understanding of what is around them even when specific visual details are beyond their visual perception. Adding the same richness of experience to the mouse pointer and computer interface has the potential to make targeting a less visually demanding activity.

Akamatsu and MacKenzie compared the effects of five different feedback conditions (none, auditory, visual, tactile, and the combination of auditory, visual and tactile) for fully sighted users in target selection tasks [1]. Although they did not find a significant improvement in target acquisition times or error rates when additional feedback was provided, users expressed a preference for redundant information over the standard interface. Furthermore, when a similar study was carried out with users placed under a visually stressed condition a significant improvement was found in user performance [9]. Redundant information along varied perceptual channels became more beneficial when the channel of visual perception was artificially narrowed. It is expected that this will also be true of computer users who have a restricted channel of visual perception due to disability.

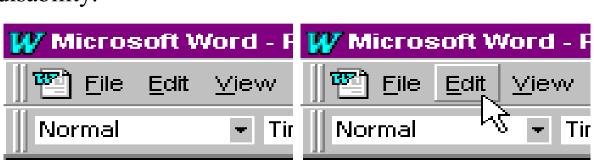

Figure 2 - On the Microsoft Word button bar buttons become raised when the pointer enters the target region (rolls over a button). This makes the target entrance event more obvious to the user by using a redundant visual cue.

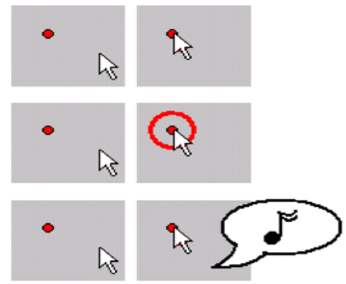

Figure 3 - Target Mouse. Assistive feedback is provided to make target enter and exit events more obvious. Feedback is only offered when the pointer enters or exits a target region. Targeting in a standard interface (top). Targeting with a visual cue (middle). Targeting with an auditory cue (bottom).

Figure 4 – Virtual Reality Mouse provides force feedback using a gravity interface. The mouse resists crossing boundaries such as window boarders, and gently draws the user toward possible targets like icons. This pointing solution exaggerate the pointer's interaction with the interface.

3.2 Second Dimension - Stage

Stage refers to the component phases of targeting that are supported by the assistive pointing solution. Stage may be locating, moving, acquiring, or any combination of the three (Table 2).

Level:	**Definition:**	**Example:**
Locating	Finding the pointer on the screen when its position is unknown.	IntelliPoint Sonar Feature [19] (Figure 5)
Moving	Moving the pointer into the general vicinity of the target.	Cursor Comet [11] (Figure 6)
Acquiring	Precisely positioning the pointer over, and recognising the successful acquisition of, the target.	RollOver – Links on the CNIB WebPage (Figure 7)

Table 2 - Summary and examples of the Stage dimension

Locating is the act of finding the mouse pointer on the computer screen when its position is unknown. When a targeting task begins, the user must first locate the mouse pointer in order to start. ***Moving*** is the act of bringing the pointer into the general vicinity of the target. It requires the user to visually follow the pointer as it changes position and travels the screen. ***Acquiring*** is the act of precisely positioning the pointer over the target, and then determining that a successful acquisition has taken place. Acquiring is the stage of targeting that requires the greatest fine motor control and attention to visual detail.

It is necessary to consider the component phases of targeting because assistance may be needed during certain phases, but not during others. Assistance offered when it is not needed can be intrusive or distracting to users [7]. Furthermore, the appropriate type of assistance must also be matched to the proper parts of any task. For example, something that helps a particular user to track the mouse pointer as it moves across the screen will not necessarily make it easier for the same user to acquire the desired target once it is reached. A pointer that leaves a trail as it changes position (as in Figure 6) exaggerates motion and can help with tracking (and possibly locating). Unfortunately, such a utility would not be expected to help a user with target acquisition. The pointer's gross motion, as represented by the trail, does nothing to make target entry and exit events more obvious.

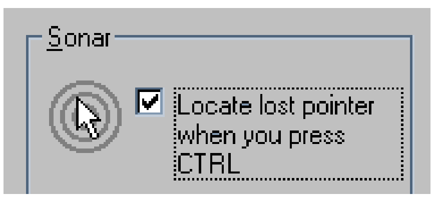

Figure 5 – Intellipoint Sonar. Cursor locator utility activated by the control key. Large circles shrink down to meet the pointer and draw the user's attention to the appropriate location [19].

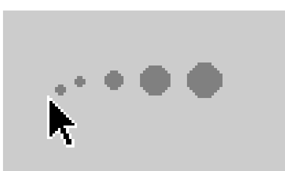

Figure 6 – Cursor Comet. A comet tail falls off behind the mouse pointer. The length of the tail is a function of speed. When moving rapidly across the screen, the visual effect of the tail exaggerates the pointer's motion. This makes the pointer's path easier for the user to follow.

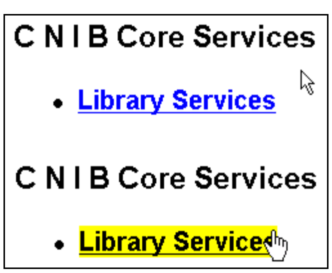

Figure 7 – Links on the CNIB (Canadian National Institute of the Blind) webpage react to indicate pointer enter and exit events. The contrast of the text changes, making it easier to read for many visually impaired users. The change in contrast exaggerates successful target acquisitions.

3.3 Third Dimension - Dependence

Dependence refers to the relationship between the pointing solution, the onscreen mouse pointer, and the interface. Assistive pointing solutions may be either interface dependent or interface independent (Table 3).

Level:	Definition:	Example:
Interface Dependent	Assistance accounts for the interaction between the mouse pointer and the interface.	Virtual Reality Mouse – Gravity Interface (Figure 4)
Interface Independent	Assistance applied to, or as a function of, the mouse pointer alone.	Colour Cursor Adjustments (Figure 9)

Table 3 - Summary and examples of the Dependence dimension.

Interface independent solutions are applied to, or are a function of, the mouse pointer alone. Interface dependent solutions account for the interaction between the mouse pointer and the interface. It is reasonable to expect that interface dependent solutions are more helpful than interface independent solutions. The user is interacting with the interface via the pointer, and so it is plausible that highlighting this interaction will be valuable. Nevertheless, the simplicity of many interface independent solutions makes them easy to implement and introduce to low vision users. Interface independent solutions like Speed Mouse (Figure 8) appear to be worthwhile areas of research.

In the real world, many assistive solutions can be considered environmentally independent. Environmentally independent solutions have assistance applied autonomously to a particular device or instrument. Large print calculators simply have bigger keys and a larger display. Specially adapted measuring devices are marked with high contrast numbers and symbols. Magnifiers work statically, and magnify the same in every circumstance - no matter what is being viewed, and no matter what the context or condition.

Often however, it is necessary for assistive real world solutions to be environmentally dependent. These solutions are often much more difficult to design, implement and use. Driving is a task that requires a great deal of visual information, spatial awareness, and monitoring of highly dynamic information such as interactions between the car and the environment. Driving is also a task that cannot be adequately adapted for most visually impaired individuals. However, adaptive solutions do exist that make it possible for the visually impaired to more easily participate in sports for example. Sporting tends to involve highly dynamic situations where the changing relationship between environmental components is important and assistive solutions must address this. Equipment that makes sounds to exaggerate its interaction with the environment and other players is an example of an environmentally dependent solution.

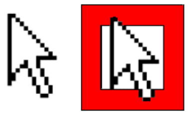

Figure 8 – Speed Mouse [8]. Particular behaviours have been observed as indicative of users who are unable to locate their mouse pointer on the desktop. These behaviours include shaking the mouse to generate an exaggerated, eye-catching motion, or "trapping" the pointer in one corner of the screen. When lost pointer behaviour is detected a red locating box appears around the mouse cursor to draw the user's attention to its location. Note that this pointing solution does not take into account the pointer's environmental context or its interaction with the interface.

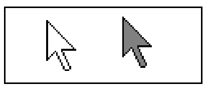

Figure 9 – Colour Adjustments. Changing its colour can sometimes improve the visibility of the pointer by improving its contrast against the background of the interface. This is an interface independent solution because it does not take into account the pointer's environmental context or its interaction with the interface.

3.4 Fourth Dimension - Pervasiveness

Pervasiveness refers to the intrusiveness and availability of the assistance. There are four suggested levels of pervasiveness: fixed, consistent, selective and requested (Table 4).

Level:	**Definition:**	**Example:**
Fixed	Assistance is provided to the user at all times and is applied directly to the mouse pointer.	Large Cursors (Figure 10)
Consistent	Assistance is always available, but it not fixed to the pointer.	Color Eyes [13] (Figure 11)
Selective	Assistance that results from only particular system events, or that is applied to only particular segments of the interface.	Target Mouse (Figure 3)
Requested	Assistance initiated when the user asks for help.	Speed Mouse [8] (Figure 9)

Table 4 - Summary of Pervasiveness dimension.

Fixed assistance is provided to the user at all times and is applied directly to the mouse pointer. Large Cursors (Figure 10) in Windows 95 for example, are always large. While using a large pointer the user is unable to ignore the assistance. Consistent assistance is always available, but it is not fixed to the pointer. The user may turn their attention to consistent assistance only when they need it. The ColorEyes (Figure 11) program is an example of a locator utility that uses consistent assistance. Selective assistance is judiciously supplied to the user. It is assistance that results from only particular system events, or that is applied to only particular segments of the interface. Requested assistance is initiated when the user asks for help. The user may explicitly ask for help in the case of cursor locator utilities that are activated by a particular keystroke (Figure 5), or the user may imply that they need assistance, as in the case of Speed Mouse (Figure 8) where particular user behaviour is considered indicative of a help needed situation.

It is difficult to say if certain levels of pervasiveness are better than others. Each appears to have its own drawbacks and strong points. Fixed solutions are easily implemented and require little or no training time. Unfortunately, fixed assistance can also get in the way when it is not needed. Consistent assistance is less likely to get in the way, but separating the pointer and the pointing aid is a challenging design requirement. Selective and reactive assistance have the added difficulty of determining when and how they should be activated.

Assistive solutions in the real world exhibit these same levels of assistance. Fixed assistance is comparative to the beeping ball sometimes used by visually impaired children to play team sports like softball. The auditory assistance is applied directly to the ball, is provided for the duration of the game, and is not easily ignored. A large print clock is an example of consistent assistance. The clock always has an enlarged display, and the low vision user turns their attention to the display only when they are interested in the time. Requested assistance is like that applied to a talking clock. To find out the time the user must press a button to make the clock read the time. Selected assistance can be likened to that provided by an alarm clock. An alarm clock or reminding device reacts to a particular date and time being reached and reminds the user accordingly.

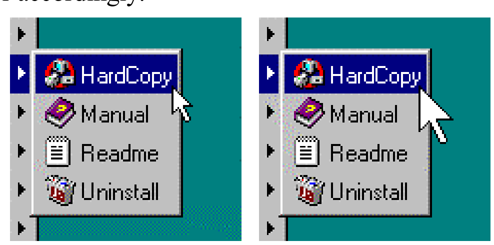

Figure 10 – Large Cursors in Windows 95/98/NT. The mouse pointer can be enlarged to improve its visibility.

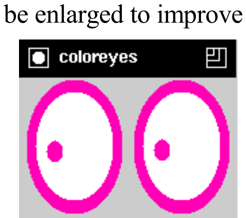

Figure 11 – ColorEyes [13]. A set of stationary eyes on the desktop "look" in the direction of the mouse pointer. As the pointer's orientation changes relative to the eyes, their gaze

changes to reflect the pointers new position. As well, as the distance of the pointer changes relative to the eyes their colour changes as a function of proximity. The user is able to calculate the pointer's approximate position by examining the state of the eyes.

4. DISCUSSION AND FUTURE WORK

It is naive to view the visually impaired as a homogeneous group of users with limited visual perception. Visual impairment is very much an umbrella term used to describe a broad spectrum individuals and abilities. Jacko and Sears [12] discuss the need to develop visual profiles of low vision users. Particular attributes and characteristics of a person's disability will make certain assistive solutions and strategies more or less applicable. There is a significant amount of work to be done exploring this area, however several trivial examples offered here:

· Magnification is not appropriate for users with a severely limited field of view. Enlarging objects further decreases the amount of the interface that is visible at one time.

· Changes in colour are very helpful for some low vision users, but of no benefit to others. High contrast colour schemes will be useful for certain types of visual disabilities, but will be even more difficult for users with other types of visual disabilities.

· Users who retain central vision are better able to ascertain fine detail and will not need to rely on other perceptual channels to the degree that users with limited central vision can be expected to.

With these examples in mind, we can expect particular regions of the design space of assistive pointers to map to certain segments of the user group, but not to others. For this reason, it is essential to have a well-populated framework of pointers whose strengths, limitations and applicability are well understood and documented. Designers should use the framework to classify, organise, describe and compare existing solutions. From this understanding of the solution space it will be possible to identify overlooked regions of the solution space, and to design new pointing solutions that fill in these gaps.

At this time, the design space of assistive pointers is not well populated. Many of the solutions cited in this paper as examples to illustrate the framework are not designed specifically with the visually impaired in mind, are part of obscure research projects or operating systems not readily available to most visually impaired users, or use technology that is not easily obtainable. The assistive pointing solutions that are readily available to users tend to be simple visibility-based solutions, and these solutions are often inadequate. Screen magnification software is cumbersome to use. Magnifying all or part of the desktop reduces the amount of screen content visible at one time. This introduces the need for the user to pan their magnified view around, causing a decrease in efficiency and the potential for disorientation. Pointer enhancement and locator utilities can also be awkward and problematic. Visually enhancing a mouse pointer by making it larger may cause the pointer to obscure other screen objects. Cursor locator utilities that are activated by a keystroke are inefficient to use since they require the user let go of the mouse in order to initiate them.

The framework proposed in this paper is only a starting point in terms of solving the pointer manipulation problem. Indeed this framework will likely expand and evolve over time as more pointers are designed, implemented and tested with actual users, and as our understanding of the problem and solution space continues to expand.

5. CONCLUSION

In this paper we presented a framework to better articulate the design space of assistive pointers for low vision users. The framework consists of four dimensions. Each dimension describes a key attributes of the assistance offered to users by any assistive pointing solution. These attributes are: the perceptual channel that carries the assistance, the stage of targeting supported by the assistance, the relationship between the assistance and the interface, and the degree of availability associated with the assistance.

REFERENCES

1. Akamatsu, M., MacKenzie, I. S., and Hasbrouq, T. A Comparison of Tactile, Auditory, and Visual Feedback in a Pointing Task using a Mouse-type Device. Ergonomics, 38, 816-827. 1995.
2. Cunningham, C, and Coombs, N. (1997). Information Access and Adaptive Technology. American Council on Education and Oryx Press, Phoenix AR.
3. Control Advancements Icn (VR Mouse) http://Control Adv.com.
4. Dix, A., et al. (1998). Human Computer Interaction: Second Eddition. Prentice Hall Europe, London.
5. Edwards, A. et al. (1995). Multiple Modalities in Adapted Interfaces. In: Extra-Ordinary Human Computer Interaction. A.D. Edward ed., Cambridge University Press, New York NY. 221-243.
6. Foley et. al. (1984) The Human Factors of Computer Graphics Interaction Techniques. IEEE Computer Graphics and Applications, 4 , 11, November 1984.
7. Fraser, J.D. (1998). Human Computer Interaction and the Low Vision User. Unpublished Directed Study Report, Technical University of Nova Scotia, Halifax NS, 1998.
8. Fraser, J.D. (1999a) Building a Better Mousetrap: An Exploration of the Design Space of Mouse Pointers for Low Vision User Computer Users. Unpublished Project Report, University of Saskatchewan, Saskatoon, SK.
9. Fraser, J.D. (1999b) The Effect of Interactive Feedback on the Efficiency of Visually Impaired Computer Users in Target Selection Tasks. Unpublished Project Report, University of Saskatchewan, Saskatoon, SK.

10. Greenstein, J. (1997) Pointing devices. In: Handbook of Human Computer Interaction. M.G. Helander, T. K. Landauer, and P. Prabhu, eds., 1317-1348, North-Holland, Amsterdam.

11. IBM (OS/2 Warp).

12. Jacko, J.A., and Sears, A. (1998). Designing Interfaces for an Overlooked User Group, Assets 98: Preceedings of the Third International ACM Conference on Assistive Technologies, (Marina del Rey CA, April 1998), ACM Press, 75 - 77.

13. Kline, R.L., and Glinert, E.P. (1995). Improving GUI Accessibility for People with Low Vision, Proceedings of ACM CHI'95 Conference on Human Factors in Computing Systems (Denver CO, May 1995), ACM Press, 14 - 121.

14. Kraut, J.A., and McCabe, C.P. (1994). The Problem of Low Vision. In: Principles and Practices of Opthalmology. D.M. Albert, F.A. Jakobiec, and N.L. Robinson, eds., 3664-3683.

15. Lansdale, M. and Ormerod, T. (1994). Understanding Interfaces, A Handbook of Human-Computer Interaction. Academic Press, London.

16. Lazzaro, J. (1993). Adaptive Technologies for the Work and Learning Environment. American Library Association, Chicago IL.

17. Lazzaro, J. (1995). Adapting PCs for Disabilities. Addison-Wesley Publishing Co., Reading MA.

18. Levack, N. (1994). Low Vision : A Resource Guide with Adaptations for Students with Visual Impairments. Texas School for the Blind and Visually Impaired, Austin TX.

19. Microsoft Corp (Microsoft IntelliPoint).

20. Newell, A. and Gregor, P. (1997). Human Computer Interfaces for People with Disabilities. In: Handbook of Human Computer Interaction. M.G. Helander, T. K. Landauer, and P. Prabhu, eds., 1003-1041, North-Holland, Amsterdam.

21. Pool, L. (1984). A Tour of the Mac Desktop. MacWorld. Vol. 1, no, 1, 1984. 16-21.

22. Weiss, B. and Moore, S. (1997). ZoomText Extra User’s Guide. AI Squared, Manchester Centre VT.

23. Woo, G.C. (1998). Patients with Low Vision. In: Borish's Clinical Refraction. William J. Benjamin ed., W.B. Saunders, Philadelphia PA. 1211-1230.

24. Zwern, A.L., and Goodrich, G.L. (1996). Virtual Computer Monitor for Visually Impaired Users, Proceedings of the 1st European Conference on Disability, Virtual Reality and Associated Technology (Maidenhead UK, July 1996).