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ABSTRACT

This paper examines graphic computing environments, identifies potential problems in providing access to blind people, and describes programs and strategies being developed to provide this access. The paper begins with an explanation of how graphic user interfaces differ from character-based systems in their use of pixels, visual metaphors such as icons and windows, locational and contextual information, and mouse-controlled interaction and random access. The paper then analyzes how much of the benefits of the graphic user interface are shared by blind users. Three stages of access to the graphic user interface are described: (1) the customizing stage; (2) the ssingle-sensory mouseless strategy for providing access to standard text, icons and simple graphics, standard graphical structures, and navigation and control; (3) the multisensory approach with a resurrected mouse, designed to extend compatibility across applications and operating systems and extend access to complex graphics and other benefits. The paper concludes that, as problems are overcome, the resulting computer access systems will provide persons who are blind with new capabilities that were not possible with earlier character-based systems. (Includes 10 references.) (JDD)

TITLE PAGE

THE GRAPHICAL USER INTERFACE CRISIS: DANGER AND OPPORTUNITY

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THE GRAPHICAL USER INTERFACE CRISIS: DANGER AND OPPORTUNITY

Abstract

The graphical user interface (GUI) is both a powerful new interface for mainstream computer users and a source of serious concern for those who cannot see. Fortunately, graphic user interfaces can eventually be as made as accessible to blind people as any of their current character-based forerunners. In addition the interface systems developed to provide this access will also provide blind computer users with new capabilities that were not possible with the character-based computers and access systems. The effects of previous inaccessibility, the current accessibility limitations, and lingering doubts as to the solubility of some of the access problems has clouded the discussion and slowed efforts to capitalize on the advantages and opportunities that these new systems might bring. The purpose of this article is to examine graphic computing environments, to identify potential new problems posed by them, and to describe some programs and strategies that are being developed to provide access to these environments.

ACCESS TO GRAPHIC USER INTERFACES BY PERSONS WHO ARE BLIND

Our intuition tells us that the more an interface is optimized for a person who can see, the less useful that computer will be to people who cannot see. Therefore, it is not surprising that many people reached the early conclusion that the new graphical computers (e.g. Apple Macintosh, Microsoft Windows, OS/2 Presentation Manager, UNIX X-Windows, etc) would eventually leave people who cannot see without adequate access to mainstream computer technology. In particular, it was widely held that blind people cannot make sense of what appears on a graphical computer screen, that they cannot interact with the computer using a mouse and pointing system, and that graphical computers are so different in basic design that even standard text cannot be understood. This in fact was the case for a jittery time when appropriate alternate interface technologies had not yet been developed. However, more recent work has shown that it is possible to design non-visual interfaces to windows, menubars, and pixel-based text. (Boyd & Boyd, 1987; Thatcher 1990) . It has also been demonstrated that tactile displays, combined with speech output, can provide direct access to simple graphics, charts, and diagrams. (Vanderheiden, 1988, 1989; Vanderheiden & Kunz, 1990). Although these programs are yet in their infancy, they have demonstrated that people who are blind can use computers with graphical interfaces and can begin exploring new capabilities not available to them on strictly character-based machines. (e.g. drawing; reading flowcharts, schematic diagrams, maps, or floor plans; reviewing or creating musical scores; etc.) Thus, while the new graphical interfaces pose new problems for access by persons who are blind, they provide new opportunities as well.

This welcome paradox cannot be appreciated without more carefully examining the following questions: What makes the graphical user interface different from the old interface? What are the benefits of the graphic user interfaces that are problems to blind people? What is the current level of access to the graphic user interface, and what programs and strategies are underway to reach the ideal of full access to all of the new features and benefits of the graphic user interface?

HOW IS THE GRAPHIC USER INTERFACE DIFFERENT FROM THE TRADITIONAL INTERFACE AND WHAT ARE ITS BENEFITS?

The graphic user interface represents a fundamental change in the way computers display information and the way that humans interact with them. Figure 1 summarizes the major categories of differences from the old interface. The most technical and fundamental difference is screen rendering architecture. The use of pixels to put images on the screen leads to the access problem of deciphering information on the screen. The second major difference involves the way that people interact with the computer. This is divided into the way that the graphic user interface represents information on the computer display and the way that users manipulate and control the flow of information. This divides access problems into those that are primarily perceptual in nature and those that relate to program/computer control.

(Figure 1 about here)

Pixels as the Technical Foundation for the Graphic User Interface

Fundamental to the graphic user interface is a basic change in the way that operating systems put information on the computer screen. Non-graphic computers (also called "character-based" computers) use a display text buffer to store information that is to be displayed on the computer screen. This buffer is a part of the computer's memory and has two numbers stored for each character position on the screen. One number represents the particular character for that position and a second number provides information regarding its color, boldness, underline etc. For example, uppercase "A", white on blue, is represented by the numbers (65,31) in memory on an IBM computer. The first number (65) is the ASCII representation of "A", and the second number (31) encodes the color information. With this type of system one can cause a character to be displayed on the screen by simply putting the proper number into the proper place in the computers memory. Conversely, one can determine what character is displayed on the screen at any point by looking at the corresponding location in the computers memory and reading the character (in ASCII) and its attribute information (color etc.) This type of system has the advantage of being very simple and straightforward. For access, it also has the advantage of providing a very easy way to access screen information. This display approach has the disadvantage that it cannot display proportional letters, different sized fonts, or diagrams, charts or pictographic information. For people who are sighted this is a restriction that makes the computer display much less flexible than what is possible and widely used on paper. It also does not allow a person to see material on the screen in the same way it will look when it is printed out on paper.

Pixel-based systems do not have a text display buffer. Instead, the representation of the screen in memory is made up of pixels (dots). To cause a character to be displayed on the screen a program sets the proper dots in memory that are needed to form the desired letter shape. In effect, images are "painted" into the computers memory as clusters (shapes) of selectively darkened pixels. The computer then uses this dot information to create the image on the computer screen. Thus, we might have a cluster or arrangement of pixels that looks like a line, circle, or square; or we might have an arrangement that looks like an "A". The advantage of this approach is that it allows any size or shaped letter as well as any type of shape, line etc. As a result, graphic images, as well as printed information that will look just like the printed version, can be displayed on the screen. This approach provides for a graphic user interface which is easier for sighted persons to use, particularly if users are not completely familiar with a computer or with a program on the computer. The major disadvantage of the pixel approach to screen rendering is that it is more complex. More pertinently, since screen information is basically a pixel-based picture of the printed words etc., rather than a listing of the characters by position, this approach poses severe but surmountable problems for access by persons who cannot see.

The Use of Visual Metaphors: Icons, Windows, Menus, Dialog Boxes, and Control Buttons

The most radical of differences between the graphic user interface and the old interface is the representation or form in which information appears on the screen. Instead of using a highly specialized command language, the graphic user interface represents information as objects or visual images that are close to immediate tasks and everyday experiences. The primary device is the visual metaphor. Figure 2 shows a typical finder level screen for the Apple Macintosh based on an office metaphor containing a desktop (with scattered piles of lists, documents, and folders), two file cabinets (a hard disk and a floppy disk), and a trash container. The computer screen presented in Figure 3 typifies the use of visual metaphors in an application, in this case, a personal checking account program. This screen shows document metaphors of a bank draft, a transaction register, a directory of frequent payees, and a directory of expenditure categories. These document metaphors enhance communication by using objects that are familiar and directly pertinent to the tasks to be performed.

(Figures 2 and 3 about here)

Locational and Contextual (Formatting) Information

Often taken for granted by sighted people, objects on a computer screen have locational as well as intrinsic properties. That is, any object can be described in terms of its location on the screen relative to the edges of the screen, relative to other objects, and relative to the pointer. For example, (as shown in Figure 2) the trash container is always located in the lower right hand corner of the screen unless you move it. The hard disk icon is immediately above the floppy disk icon. The Edit heading is located at the top of the screen, on the left, between the File and the View headings. This kind of information greatly facilitates finding something when you want it. This is consistent with the way we tend to organize our daily work environments.

The spacial arrangement of objects convey meaning in other ways too as in the formatting of documents, where paragraphs, columns, spacing, headings, indentations, footers, and other formatting devices convey meaning. Also, properties of degree are often communicated by an object's relative location on the screen and relational properties between objects such as relative importance, similarity, and belongingness are often communicated by the location of the objects relative to each other.

Mouse Controlled Interaction, Screen Navigation, and Random Access

The lower branch of Figure 1 identifies another feature of the typical graphic user interface that sharply distinguishes it from traditional interfaces. That feature is the way that it provides for user control and interaction between the computer and user. With early traditional interfaces, one had no choice but to learn the keyboard commands and procedures for each application used. Commands and file names were typically typed again and again each time they were run or opened. Often, interaction with the machine required a tedious dialog of prompts and typed verbal commands. The graphic user interface takes an entirely different approach. A mouse is moved about a surface area such as a mousepad. Moving the mouse toward the right edge of the mousepad moves a pointer toward the right edge of the screen. Moving the mouse toward the bottom edge of the mouse pad moves the pointer toward the bottom edge of the screen. To select something on the screen, the pointer is moved over the object and the mouse button is clicked. This quick and direct access of programs, files, and commands is sometimes referred to as "random access."

Commands and entries are made the same way. For example, in the checking account example shown in Figure 3, a typical action would be to move the pointer over the "Transactions" heading in the menu bar, pull that menu down (by holding down the mouse button), move the pointer over the desired transaction, and release the mouse button. For check entries, you would move the pointer over the appropriate blank space on the the check, click the mouse button, and enter the appropriate text, such as check number, payee, date, amount, and expenditure category. For recurrent check transactions, you can point to the payee's name on a list of frequent payees, click the mouse button, and have the vital parts of the check filled out automatically. Completed transactions can be reviewed in a check register. In like manner, checks can be cut, accounts reconciled, changes made, and transactions summarized on tables or graphs, all by pointing, clicking, and entering text.

The Standardized Interface

The screen rendering capabilities of graphical computers facilitates the ideal of one interface for all applications. Increasingly, the tools for rendering graphical images on the screen and the tools for the mouse control of information flow are provided by the operating system. Consequently, instead of designing and coding a new interface for every application, the application makers simply say, "Draw a menu bar here", "a window here", "a dialog box here", a "button here", and so forth. The benefits of a consistent interface to developers are convenience and reduced development, documentation, and support costs. The great advantage of the standardized interface for users is that they do not have to start from scratch every time they try a new application. This same standardization of interface is possible with character-based screens, but because of the simplicity of screen access, most developers chose to go their own directions. In one sense the complexity of the graphic user interface has facilitated the use of a standard approach by developers. The standardized interface has critical implications for providing access to the graphic user interface by blind people. Specifically, knowing in advance how and where things are done in the interface of most applications makes it possible and practical for third party developers to tap into the flow of information in the graphic user interface and direct it to blind users through nonvisual channels.

HOW GOOD IS CONTEMPORARY ACCESS TO GRAPHICAL COMPUTERS?

The New and Only Meaningful Measure: How Much of the Benefits of the Graphic User Interface Are Shared by Blind Users?

Only a short while ago there was no way for people without sight to access graphical computers. Today there is. However, unlike traditional interfaces, it is not useful to think of access as an either/or proposition. What we really want to know is the degree to which specific access systems and new strategies provide blind people access to graphic user interface based computers. Specifically, we want to know which of the benefits of the graphic user interface identified above are shared by users who are blind and at what levels. Also, as a longer range ideal, we would like to know how compatible an access system is across operating systems and how amenable it is to modification by third parties and individuals to respond to new situations and needs. It must also be kept in mind that these new access approaches need to provide access not just to textual information but to graphical (diagrams, charts, etc) information as well. This is information which was inaccessible with character-based access systems. Direct comparisons of access to graphic user interface computers with access to previous computers therefore can be somewhat misleading unless access to graphics on the text-based computers is taken into consideration.

Having to meet both coverage and degree criteria, access systems theoretically could vary almost infinitely. However, for practical purposes, it is useful to think in terms of four general levels of access. This evaluation scheme is presented in Figure 4.

(Figure 4 about here)

Stages of Access to the Graphic User Interface for the Blind

In general, there have been three major periods or stages of development: a customizing stage, a single sensory stage, and a multi-sensory stage. This framework outlined in Figure 5 summarizes the progression of goals and strategies of the three stages. In brief, they evolve toward higher levels of access which, in general, tend to coincide with the levels of access described in Figure 4. Stage I and Stage II are based primarily on software only, on one adaptive aid (a screen reader or braille translator), and on one nonvisual channel (either speech output or braille). Stage III is based on a multi-sensory approach with a combination of adaptive hardware and software.

(Figure 5 about here)

Stage I: The Customizing Stage

Stage I access was not characterized by a particular specific system but rather a number of commercial applications having the same general strategy -- which was essentially a coping strategy. In these applications, only level 1 access is pursued (see Figure 4) and most of the benefits of the graphic user interface were unrealized for blind people. In general, the sole purpose was to enable blind people in very specialized ways to read straight text produced on graphical computers through speech or braille. The problem which was confronted was the change in the screen-drawing architecture of graphical computers. Specifically, in the absence of a text buffer, conventional screen readers do not have readily available screen information in ASCII form to pass on to blind users via speech or braille. As one observer put it tersely only a short while ago:

> ... the Macintosh uses a graphical interface that is essentially inaccessible to the blind: the Mac's screen memory contains only raw information about each pixel, and the

> screen readers can't make sense of the bit-mapped display. The more graphical the interface, the less translatable it is into speech. A screen full of icons, pictures, and overlapping windows becomes gibberish to a screen-reading program seeking clean ASCII code. To the extent that DOS and OS/2 emulate the Mac's graphical interface, the blind will soon be locked out of PCs as well" (Brody, July, 1989).

Generally speaking, Stage I development consists of attempts to deal with the pixel problem by rewriting or modifying selected applications. The strategy was to selectively access information from within the program (where text information is known) rather than providing general access to the system or user interface. A good example of the thinking of this stage is a braille translator on the Apple Macintosh which consists of software that inputs standard text or ASCII files and translates them into braille. The obvious benefit of the translator approach is that it enables blind people to read documents produced by word processing applications. It can also be used with optical character recognition devices to translate paper documents into braille or speech. Therefore, it is valuable for providing blind persons access to documents produced on the Macintosh, and can be a valuable desktop publishing tool for braille libraries. Its most serious limitation is that it makes no attempt to interpret screen information in real time or to actually use the Macintosh interface for control and navigation. As a result the user has access to portions of the output of the program but not to the system overall or to other programs.

Stage II: The Single-Sensory Mouseless Strategy:

Providing General Access to Standard Text

The major objective of Stage II work was to provide level 2 access. Its central aim was to provide access to standard text across a wide number of applications. This aim became reality with the first general solution to the "pixel problem" which became known as the "interception strategy." Instead of trying to make sense of pixel-drawn information, this approach snares ASCII information before it gets to the screen. On pixel-based machines, readable ASCII information is provided by the application at the point where screen writing services are called. This information is intercepted, modified, and stored in a special "off-screen buffer" before it is discarded by the screen writing services. This buffer is monitored and updated to provide speech-based screen access. The first commercial application of the interception approach was outSPOKEN™ for the Apple Macintosh (Boyd & Boyd, 1987).

Providing General Access to Icons and Simple Graphics

In addition to access to straight text, Stage II efforts sought the ability to recognize icons and simple graphics in standard applications. This required both technical and perceptual solutions in that the operating system must be able to identify the objects on the screen and communicate that information to people through nonvisual means. However, it is important to put this problem into perspective.

One of the natural fears of people who are blind is that the trend in computers is toward total "pictographic" communication where visual metaphors completely replace words. In reality, the most predominant trend is toward pictures accompanied by words. This combination of pictorial and textual information provides more information and makes finding things easier, faster, and more reliable. For a tactile comparison, imagine all the groceries in a cupboard as having a braille label on them. Now imagine that all of the groceries (ketchup, beans, cereal, flour, etc) were all stored in cubes that were the same size and shape. As long as everything had a textual (braille) label, it could be eventually found and identified. Storing different types of things in different places would also help. But finding things that differed only by their textual labels would be harder than if they also had differing shapes (ketchup in bottles, beans in round cans, cereal in different sized boxes, flour in a bag, etc.). Adding shape cues would provide searchers who were blind with additional cues which could make their searches faster, easier, and more accurate. The use of visual icons to accompany text labels can serve the same purpose for sighted users as tactile shape can for blind users.

The use of icons is also not nearly as extensive as sometimes imagined. For example, all of the generic icons used at the finder level of the Macintosh can be counted on two hands (trash container icon, disk icon, document icon, program icon, window, close and resize box, and scroll bar). Almost all of these icons have word labels attached which can be read by interception-based access software. The rest can be easily recognized electronically and a name can be attached to them.

While a wider variety of icons is used to represent particular applications, it is not necessary for a blind person to perceive the shape of the icons to use them. All that the blind person needs to know is the fact that the pointer is over an object that represents an application whose name name is X. The names of the applications are readable with interception-based software. Simple graphs and charts are more problematic but they are just as problematic with character-based screen access systems where they are used. Fortunately, graphs and charts often complement rather than replace text. Also, with spread sheets and data analysis applications, one often has the choice of having information summarized in a table containing text or in a bar graph or pie chart.

A frequent concern is how a speech-based screen reader can handle para-linguistic text such as fonts, italics, highlighting, underlining, and so forth. The interception-based software of Stage II recognizes and tracks this information and communicates it to the blind user by changing the pitch of voice output when a change is encountered. If desired, the user can then get specific information of this kind by a designated keystroke.

Providing General Access to Standard Graphical Structures

An important event in Stage II development was the use the interception strategy of outSPOKEN to recognize and track information about windows, menus, dialog boxes, control buttons, and scroll bars. Information including type, status, size, location, and content of these standard graphical structures is stored in the off-screen buffer along with ASCII information about text, icons, and simple graphics. This information is conveyed to the blind user through speech when it is encountered by the screen review process of outSPOKEN or when solicited by the user. This capability is essential to the general access of graphic user interface computers across applications. While it is currently confined to the Apple Macintosh operating system, development on other operating systems is underway.

Providing a Mouseless Navigation and Control System

The approach to the so-called mouse problem taken in Stage II was to circumvent it. That approach substituted the manual functions of the mouse with keystrokes on the number pad of the keyboard. With the eighteen keys on the number pad, the blind user can perform most of the standard control functions of the mouse. This includes reviewing the desktop, reviewing the menu bar, selecting commands under menu columns, activating windows, moving the pointer incrementally across or down the screen, putting the pointer over desired objects, selecting them, dragging them, reshaping them, launching applications, reviewing, writing, and editing text. Another keystroke pulls down a list of windows opened on the screen and another steps the pointer through the options. Others are used to activate windows, review the options in windows, select them, and launch them. This approach also provides a "find" keystroke that takes typed input and moves the pointer over the desired object. To facilitate window management and between-window operations, it provides keystroke functions that resize and reshape windows to the user's specifications.

Mimicking the Functionalities of Locational and Contextual Information

The speech-based access software of outSPOKEN attempts to capture the functionalities of locational and contextual information in several ways. One is to verbally inform users when the pointer is moved to any of the screen's edges. Absolute screen location is provided by a function key that voices the screen coordinates of the pointer when it is pressed. In combination with a keystroke that tells what is under the pointer, blind users can mentally pinpoint the location of objects for subsequent reference. Information about pointer and insertion bar locations within windows is also provided by keystrokes. This is particularly important when working with documents. outSPOKEN provides format information indirectly through para-linguistic cues, such as the occurrence of bold-faced letters in headings, and through auditory cues such as beeps to signal the end of a line or column of text. More direct information includes the number of empty lines encountered between lines of text and the number of lines in a selected window.

Locational information also comes with the standardized interface by learning the conventions of where objects usually appears. For example, the trash container on the Macintosh desktop is always in the lower right corner (unless you move it). Another more indirect source of locational information comes with moving the pointer to the right or left and up or down and identifying what is under the pointer at various points. In this way, the blind user can reconstruct in his or her mind the screen locations of objects relative to each other.

Major Shortfalls of Stage II Access

Developments in Stage II fell short of the goal of providing blind people full access to graphical computers in six major ways:

1) The interception strategy does not work with all applications. This is the result of incompatibilities between application software and access software that occur when application developers write their own interfaces. The popular authoring application called HyperCard™ is a notable example of inaccessibility with systems based on the interception strategy.
2) The speech-based strategy of outSPOKEN cannot interpret and communicate complex graphical information to blind people.
3) In its present form, outSPOKEN cannot respond to new demands or be adapted by third parties or individuals to fit special needs and changing situations.
4) The interception strategy is not easily applied to platforms other than the Macintosh.
5) The single sensory strategy does not provide the full benefits of the scanning, browsing, memory jogging functions of the graphic user interface nor the full benefits of locational and formatting information.
6) The keyboard approach does not enable the blind person to use the mouse for navigation and control, for spacial location, and for recognizing complex graphics.

Stage III: The Multi-sensory Approach with a Resurrected Mouse

Extending Compatibility Across Applications and Operating Systems

Two different strategies are being pursued in Stage III development to solve the compatibility problems of the first version of outSPOKEN. The most immediate and practical approach is to redesign the structure of outSPOKEN to make it modular, more generic in concept and structure, and more easily modified to meet new demands and special needs. New design criteria will more explicitly anticipate its role and integration in the multisensory- multimedia approach of Stage III. Among the specific goals is to make HyperCard and HyperText and other previously inaccessible applications accessible. A related objective is to make it easier for third parties and end users to access the workings of access software to fit personal needs and unanticipated uses and situations. The strategy selected for accomplishing this is to enable HyperText scripting to be used to re-shape the access software. The long term objective of this effort is to lay the groundwork for compatibility across operating systems.

The second major approach to solving the compatibility restrictions of earlier stages of development is to interpret information after it is rendered in pixel form. Theoretically this could be the ultimate solution to making access technology completely independent of platforms and operating systems. This potential is currently being explored under the new name of VRT or "Video-image Recognition Technology" (Boyd & Boyd 1990). In brief, this technology seeks to adapt optical character recognition (OCR) memory scanning algorithms to interpret internally generated bit-mapped video display information for standard text. For more complex images it adapts and develops new AI (artificial intelligence) and pattern recognition techniques. This information is stored in off-screen text buffers analogous to the interception-based software. The advantage of this approach is that screen information can be interpreted regardless of what screen-rendering technology was used to put it on the screen. The downside is that practical applications are much further off than for the first approach.

Extending Access to Complex graphics and Other Benefits of the Graphic User Interface

Most of the shortcomings of Stage II development directly or indirectly involve the perceptual and navigation problems associated with the inadequacy of speech-based access alone. Stage III development seeks to capture the enhanced functionalities of the graphic user interface through a multi-sensory approach that integrates and expands technology developed for tactile-based access devices (Vanderheiden, 1988, 1989; Vanderheiden & Kunz, 1990). In particular, it builds on the product called Optacon II™ by Telesensory Systems which directly presents a tactile image of text (and lines, graphics, etc) to a blind user through a set of vibrating pins. This approach avoids the problem of requiring a third party or the computer to interpret visual images because it leaves that task to the user. This technology, first developed with the optical scanning of documents in mind, was adapted to the transmission of pixel-based computer screens by the product called inTOUCH™. This software allows one to "feel" screen images on the tactile device as the mouse moves the pointer about the screen.

The major problem with using Optacon II for computer access is that it ties up two hands -- one on the mouse and one on the vibrating pin device. A second problem is that the mouse is a relative pointing device. That is, you use the mouse to tell a pointer on the screen to move up, down left or right from where it is but you get no tactile or kinesthetic feedback as to where you are pointing. To solve these problem, the Trace Center has developed a device that puts the vibrating pins of Optacon II on top of an absolute reference pointing device (similar in function to a graphics tablet puck). With this device, now called the "tactile puck/mouse," the blind person can feel under a fingertip the vibrating image of the pixel images that the pointer is passing over by the movement of the puck/mouse. The effect is a virtual full page tactile image of the screen. The resurrection of the puck/mouse to provide screen information through a channel other than speech is a central ingredient in Stage III efforts to increase the blind person's ability to interpret complex graphical images on the graphic user interface. It also restores more of the functionalities of scanning, browsing, and memory jogging, and thereby, more of the benefits of the graphic user interface.

Another inadequacy of Stage II access that the tactile puck/mouse addresses is the loss of orientation, location, and context (formatting) information when a user is blind. Specifically, the problem with speech-based solutions only is that it is difficult to continuously keep track of where things are on the screen. The tactile puck/mouse (which also, on command, reads information aloud as it is touched on the screen) provides a quick way to explore the screen and provides the user with kinesthetic feedback as to location. With it the blind person can piece together mental images of where things are on the screen. This partially restored functionality is supported by another innovation that introduces the concept of haptic feedback (as a substitute for visual feedback). An application of this approach is the development of a new kind of mouse tablet that is made to correspond directly to the screen and a puck/mouse whose relative position on the tablet corresponds directly to the relative position of the pointer on the computer screen (Vanderheiden, 1988,1989). Thus, if the puck/mouse is at the upper left corner of the table, the pointer will be at the upper left corner of the screen.

This haptic locational information can be further reenforced through the use of 3 dimensional sound reproduction (Boyd, 1989; Stevenson, 1989; Vanderheiden, 1989; Vanderheiden & Kunz, 1990; Gehring & Morgan, 1990). With this approach, the words being spoken sound like they are coming from the location on the screen where they are located. As you read from left to right, the voice seems to float from left to right. If a word is heard coming from the right, you know you will find it on the screen on the right edge. These audio location cues can either provide direct locational information or reenforce haptic locational cues.

To further accelerate input and control by users who are blind, the new interfaces being explored include tactile ribbings engineered into the surface of the virtual tactile tablet to provide points of reference between the edges and cardinal points. It is also outfitted with a row of "virtual buttons" then can be dynamically defined to provide fingertip availability of frequently used files and operations, macros etc. Multi-sensory systems are also under development that incorporate voice recognition for many of the repetitive user commands and operations (Vanderheiden, 1988,1989; Vanderheiden & Kunz, 1990). This frees up the user's hands and mind to concentrate on other things. But, the ideal is still to restore the functionalities of the mouse that are not simply command functions. In particular, the ability to rapidly maneuver the pointer back and forth over and around objects on the screen with continuous (tactile, audio and haptic) feedback through the tactile/sonic/talking mouse/puck provides an important alternate nonvisual potential for interpreting pure and mixed graphics. It also provides the first opportunity for persons who are blind to explore drawing and other creative graphic activities.

WHAT LIES AHEAD?

It is about as certain as anything ever is in the computer business, that the graphic user interface is here to stay. It is also predictable that the graphic user interface will become even more dependent on vision as the industry moves toward multimedia live action and animation. An example, is an interface glove that users will wear to move files, turn pages, punch buttons, and other such things. These will continue to pose new problems and require new strategies to overcome them. As the problems arise they will take the form of new barriers. As we overcome them however, the resulting computer access systems will provide persons who are blind with new capabilities that were not possible with earlier systems. For example, just as the systems discussed in this paper can provide a person who is blind with the ability to feel charts, floor plans, maps etc, newer systems based on 3 dimensional tactile and auditory displays may provide the ability to mentally construct the shape of a new car or other object "displayed" by a computer. When thinking about advances in computer architecture and accessibility by persons with disabilities it is useful to remember that the Chinese symbol for crisis is a combination of the symbol for danger combined with the symbol for opportunity.

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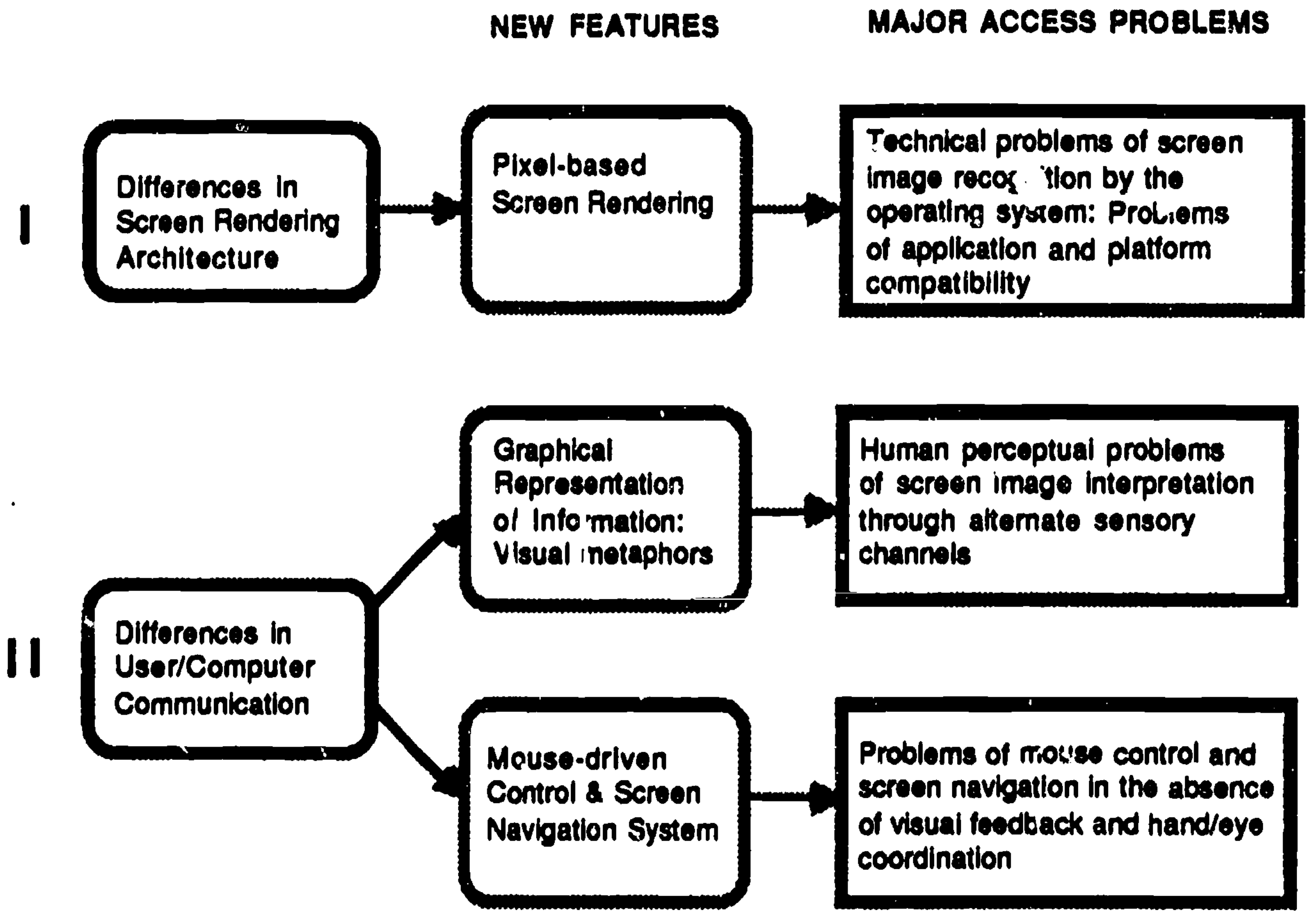


Figure 1. Major Differences Between the GUI and Traditional User Interfaces With General Categories of Features and Access Problems for Blind Users

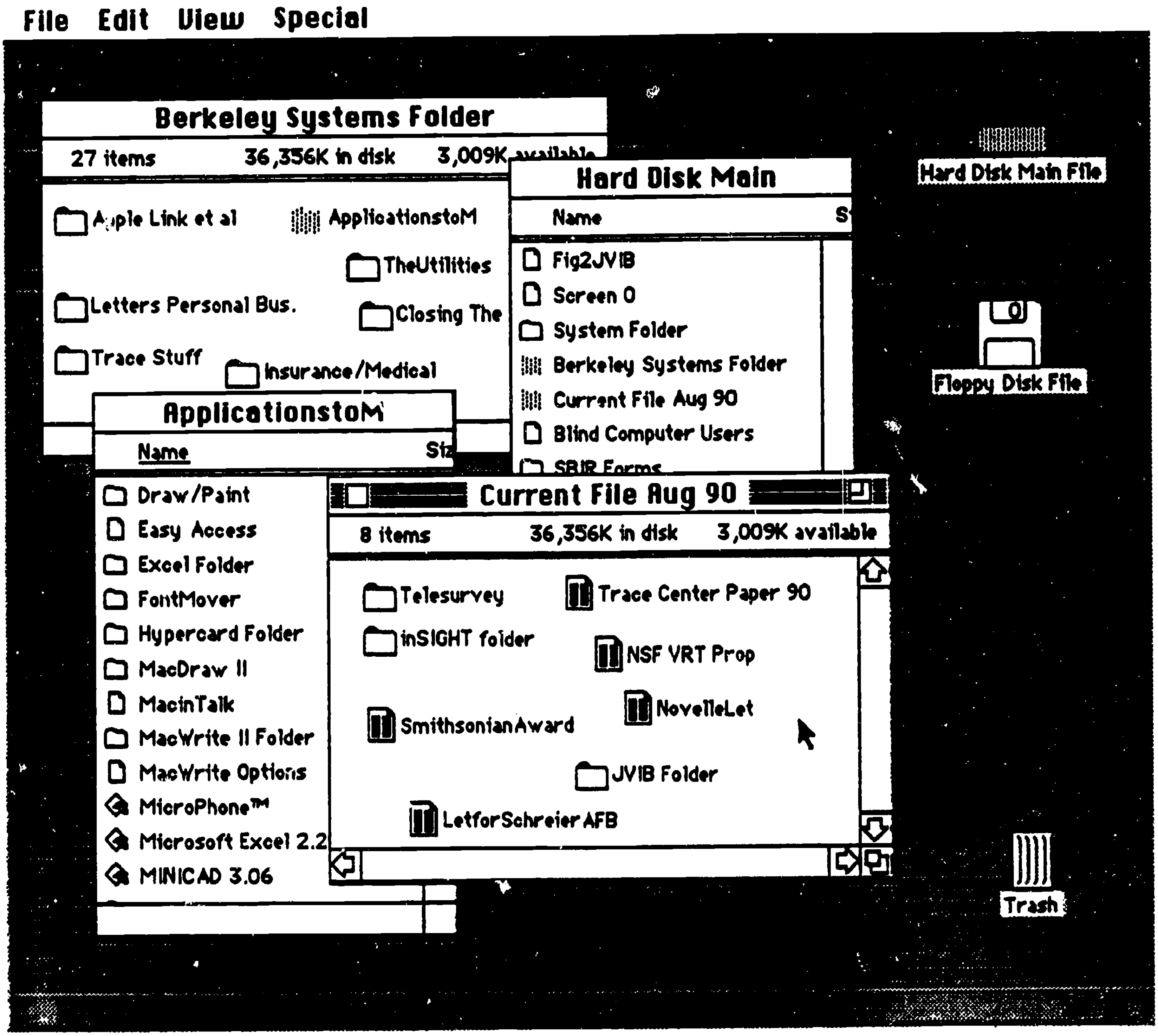
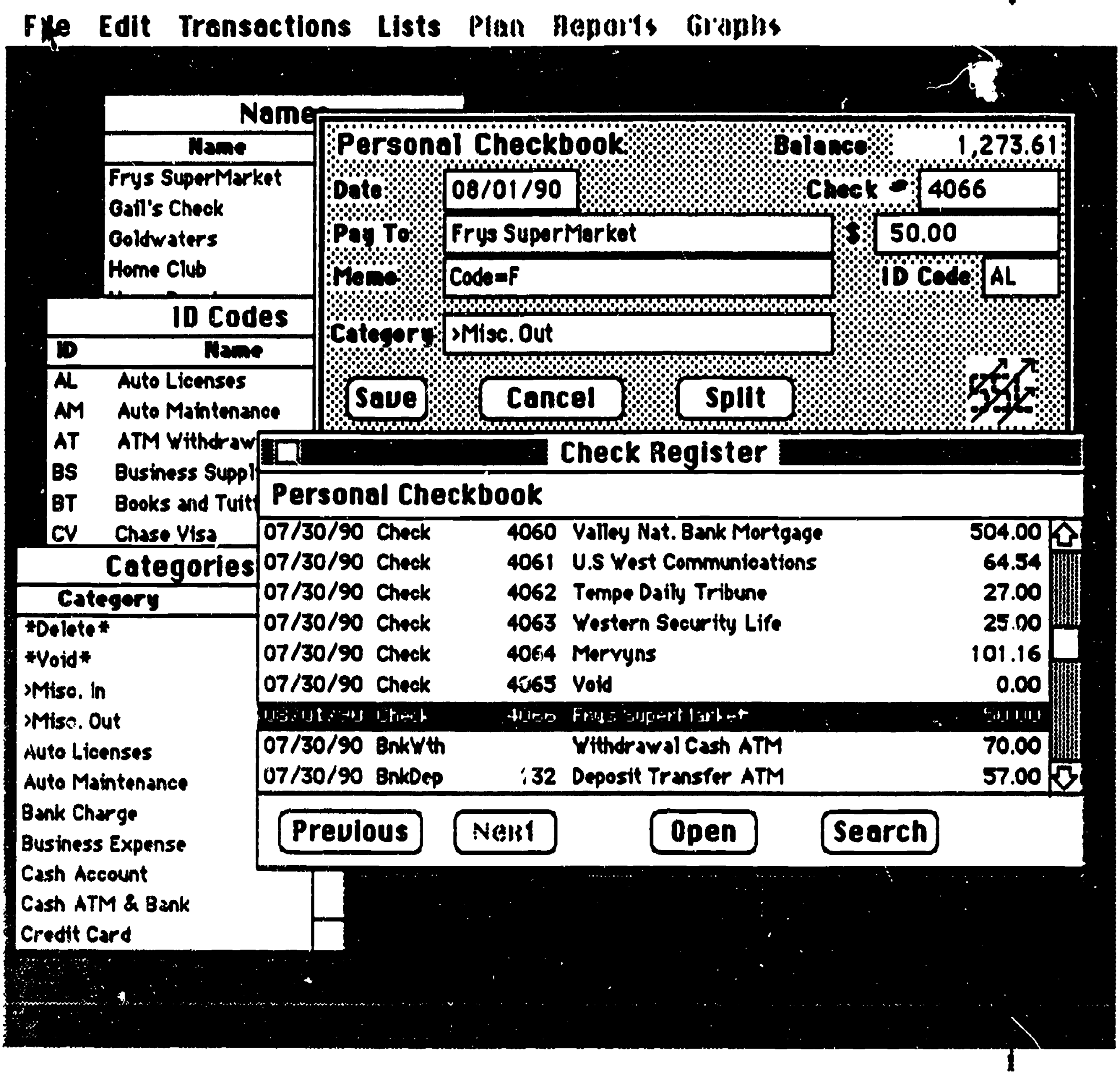


Figure 2. Typical File Finder Screen of a Graphical User Interface



Name
Frys SuperMarket
Gail's Check
Goldwaters
Home Club

ID Codes

ID	Name
AL	Auto Licenses
AM	Auto Maintenance
AT	ATM Withdraw
BS	Business Suppl
BT	Books and Tuit
CV	Chase Visa

Categories

Category
Delete
Void
>Misc. In
>Misc. Out
Auto Licenses
Auto Maintenance
Bank Charge
Business Expense
Cash Account
Cash ATM & Bank
Credit Card

Personal Checkbook

Balance 1,273.61
Date 08/01/90
Check # 4066
Pay To Frys SuperMarket
$ 50.00
Memo Code=F
ID Code AL
Category >Misc. Out

Personal Checkbook

07/30/90	Check	4060	Valley Nat. Bank Mortgage	504.00
07/30/90	Check	4061	U.S West Communications	64.54
07/30/90	Check	4062	Tempe Daily Tribune	27.00
07/30/90	Check	4063	Western Security Life	25.00
07/30/90	Check	4064	Mervyns	101.16
07/30/90	Check	4065	Void	0.00
08/01/90	Check	4066	Frys SuperMarket	50.00
07/30/90	BnkWth		Withdrawal Cash ATM	70.00
07/30/90	BnkDep	132	Deposit Transfer ATM	57.00

Figure 3. Typical Screen Within an Application Showing Windows, Menus, and Buttons

Level 1 Access	General: Restricted to one operating system and one application. Difficult or impossible for third parties or individuals to adapt to new situations & needs. Specific: Can recognize and manipulate standard text in highly specialized and isolated situations.
Level 2 Access	General: Restricted to one operating system. Applies to a wide range of applications. Specific: Can recognize and manipulate standard text. Can recognize icons and simple graphics. Can recognize pulldown menus, windows, popup dialog boxes, and buttons. Can move about the screen and manipulate screen objects (without the mouse). Limited ability to scan and browse screen information. Limited ability to perceive locational and contextual (formatting) screen information.
Level 3 Access	General: Easily adapted across operating systems. Applies to most applications and easily adaptable to special cases. Specific: Can interpret some standard complex graphics such as bar graphs and pie charts. Can use the mouse and pointer for orientation, navigation, and control. Can scan and browse screen information. Can perceive locational and contextual (formatting) screen information.
Level 4 Access	General: Applies across all operating systems. Applies across all applications Allows third party developers and individuals to modify to fit special needs and new situations Specific: Provides all of the functionalities of the GUI at the same levels as for sighted people.

Figure 4. Levels of Access to the Graphic User Interface

STAGE I

Seeks Level 1 Access: Restricted to one operating system.
Usually a customized approach for one application.
Limited to interpreting standard text.
Based primarily on software.
Based primarily on one adaptive aid: Screen reader or braille translator.
Based primarily on one alternate sensory channel: Speech output or braille.

STAGE II

Seeks Level 2 Access: Restricted to one operating system.
Applies to a wide range of applications
Interprets standard text, simple icons.
Can recognize and manipulate windows etc.
Navigates by keystroke navigation system
Limited browsing and format perception
Based primarily on software.
Based primarily on one adaptive aid: Screen reader or braille translator.
Based primarily on one nonvisual sensory channel: Speech output or braille.

STAGE III

Seeks Level 3 Access : Maximum operating system independence.
& Compatibility with all applications.
Level 4 Access Can interpret graphs and charts.
Can interpret complex drawings.
Full browsing and locational capabilities
Full mouse control.
Supplementary voice input control.
Easy modifiability by Third parties and individuals.
Uses both software and hardware.
Modifies and integrates adaptive aids.
Integrates multiple nonvisual communication channels:
Speech output, Voice recognition, Tactile & Haptics& Auditory cues

Figure 5. Major Features of Access STAGES I, II, and III

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