VOICE AND TOUCH DIAGRAMS (VATAGRAMS): DIAGRAMS FOR THE VISUALLY IMPAIRED

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By

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ABSTRACT

If a picture is worth a thousand words would you rather read the two pages of text or simply view the image? Most would choose to view the image; however, for the visually impaired this isn’t always an option.

Diagrams assist people in visualizing relationships between objects. Most often these diagrams act as a source for quickly referencing information about relationships. Diagrams are highly visual and as such, there are few tools to support diagram creation for visually impaired individuals. To allow the visually impaired the ability to share the same advantages in school and work as sighted colleagues, an accessible diagram tool is needed.

A suitable tool for the visually impaired to create diagrams should allow these individuals to:

1. easily define the type of relationship based diagram to be created,
2. easily create the components of a relationship based diagram,
3. easily modify the components of a relationship based diagram,
4. quickly understand the structure of a relationship based diagram,
5. create a visual representation which can be used by the sighted, and
6. easily accesses reference points for tracking diagram components.

To do this a series of prototypes of a tool were developed that allow visually impaired users the ability to read, create, modify and share relationship based diagrams using sound and gestural touches. This was accomplished by creating a series of applications that could be run on an iPad using an overlay that restricts the areas in which a user can perform gestures.

These prototypes were tested for usability using measures of efficiency, effectiveness and satisfaction. The prototypes were tested with visually impaired, blindfolded and sighted participants. The results of the evaluation indicate that the prototypes contain the main building blocks that can be used to complete a fully functioning application to be used on an iPad.

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My parents and sisters: Gerry, Win, Natasha and Tessa

My grandparents: I wish you had been here to see me succeed. Baba I am glad you were able to see me start the program.

All my aunts, uncles, cousins, nieces and nephew.

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CHAPTER 1

1 INTRODUCTION

If a picture is worth a thousand words would you rather read the two pages of text or simply view the image? Most would choose the image; however, for the visually impaired this isn't always an option.

Being visually impaired covers everything from low vision to blindness. Low vision includes hazy or blurred vision, central scotomas (loss of detailed central vision) and peripheral scotomas (loss of detailed peripheral vision) (Faye, 2008). Low vision is sight which is worse than 20/70 but as good as or better than 20/200. Blindness includes sight which is worse than 20/200 vision up to no light perception. Like low vision, blindness can affect central, peripheral or entire visual fields. (Whitcher, 2008).

In 2006 Statistics Canada reported that there were approximately 816, 250 people over the age of 15 who professed to having seeing limitations (being visually impaired) in Canada. Of these people, only 1/3 were employed even though 40% attended some form of post secondary education. Over half the employed visually impaired persons reported that they are limited by the type of work they can perform (Statistics Canada, 2006). In order to create equal opportunity in our changing technically advanced society, there is a need to support the visually impaired in their education and careers. This needs to be done in such a way as to increase their independence and maximize their potential.

Computers have become mainstream in educational institutions and office environments. Currently, "[t]he main technology that visually impaired users use to access a computer is a screen reader" (Cohen et al, 2005). Screen reader software runs behind other applications and reads text that appears on the screen. Unfortunately screen readers can fail when accessing computer programs designed without screen readers in mind. Screen readers are unable to provide context and cannot read images (unless underlying coding provides a description, i.e. an alt tag).

1.1 MOTIVATION

A diagram is a drawing or picture which explains how something works and can often clarify the relationship between different parts (dictionary.com). Carney and Levin (2002) suggest that pictures can act as adjunct aids for texts and provide learning benefits such as perceiving, understanding and remembering. Peeck (1993) suggests that the information retention may be enhanced by a picture's abilities to motivate, focus and induce processing in readers as well as clarify material. The most effective diagrams engage learners in the cognitive process (Butcher and Kintsch, 2004; see also Carney and Levin, 2002).

Diagrams are a tool the sighted have used in various fields including business, science and art. Diagrams help one to understand complex information and relationships more quickly than using a word description alone. For example, in the area of databases, a database administrator may use an ER-Diagram (Entity Relationship) to quickly obtain an overview regarding the organization of a database.

There are insufficient tools for the visually impaired to deal with disciplines which are visually intensive. In his experience working with a blind computer science student, Connelly (2010) found that his student relied heavily on a tutor. He found it particularly difficult to teach this student in the database class because the discipline is largely diagram based (Connelly, 2010). Another example of this problem was noted by one software engineer who said that she "had been made redundant when her department switched to UML, as she was unable to visualize the diagrams" (Horstmann et al, 2004). These problems need to be alleviated.

When asked what the main reason for unmet needs in relation to assistive technologies, 38% of individuals answered that cost was the main barrier (Statistics Canada, 2006). Mcgookin et al (2008) had similar results from their questionnaires and noted that a respondent commented on the fact that "an awful lot of assistive technology is far too expensive" (Mcgookin, D., Brewster, S., and Jiang, W., Nordichi 2008). For example, an iVeo Touchpad and software used for creating and viewing tactile images is $995 USD. You also need a tactile overlay and to make these yourself you would need a Braille printer which runs around $3,995 (http://www.viewplus.com – June 15, 2010). Comparing the costs of the iVeo Touchpad and the Braille printer to the iPad, which is a mass consumer item, the iPad's entry level is pricing is only $499 USD (Apple.com) and it is used for much more than just reading images.

When designing products to be used by people with various abilities the question often becomes how much should one support? Perhaps Vanderheiden and Henry (2001) said it best when they stated:

> No single interface technique will work. Creating an everyone interface sounds wonderful, but it can sound unobtainable. Trying to design to a single least common denominator interface clearly does not work. If we use only those abilities or input techniques that everyone has and can use in any environment we would have to rule out all visual, auditory, and tactile interfaces. (Vanderheiden and Henry, 2001)

1.2 THESIS STATEMENT

In order to be competitive in the job market and learn fully in their field of study, Visually Impaired persons require the ability to read, create, and modify diagrams as well as share them with sighted users. Current diagram systems created for the visually impaired are not specifically built for creating and reading a variety of relationship based diagrams and they often require the intervention of a sighted person. These programs are more concerned with describing the detailed visual aspects of the diagram than they are with providing the user with benefits similar to those experienced by the sighted.

1.3 APPROACH

Diagrams assist people in visualizing relationships between objects. Most often these diagrams act as a source for quickly referencing information about relationships. Diagrams are highly visual and as such, there are few tools to support diagram creation for visually impaired individuals. To allow the visually impaired the ability to share the same advantages in school and work as sighted colleagues, an accessible diagram tool is needed.

A suitable tool for the visually impaired to create diagrams should allow these individuals to:

1. easily define the type of relationship based diagram to be created,
2. easily create the components of a relationship based diagram,
3. easily modify the components of a relationship based diagram,
4. quickly understand the structure of a relationship based diagram
5. create a visual representation which can be used by the sighted, and
6. track existing relationship based diagram components by using easily accessible reference points.

To do this a prototype of a tool was developed that allows visually impaired users the ability to read, create, modify and share relationship based diagrams using sound and gestural touches.

1.4 CONTRIBUTIONS

By creating a tool that allows the visually impaired the ability to create and read diagrams the following contributions are:

1. Guidance for presenting diagrams to the visually impaired.
2. A prototype of a tool that provides the basic structure which would lead to creating a completely functional tool; enabling the ability to read and create relationship based diagrams.
3. An understandable verbal representation of relationship based diagrams.
4. Verbal diagrams that can be navigated tacitly
5. Design of a tactile overlay grid and input system allowing one to navigate Diagrams.

1.5 OUTLINE

The flow of this thesis consists of six more chapters. Chapter 2 introduces the area of accessibility for the visually impaired. This chapter provides background information about diagrams and summarizes related work. Chapter 3 lists the requirements to build a system to meet the unique needs identified in the introduction. The design and evaluation of an overlay that is placed over the iPad screen will be discussed in Chapter 4. The design of the prototypes and the evaluation of the prototypes are presented in Chapter 5 and Chapter 6. Finally Chapter 7 will conclude this thesis with a discussion and listing of future work.

CHAPTER 2

2 RELATED WORK

This chapter provides the background for this thesis. An overview of diagramming is provided as well as descriptions of existing systems that provide the visually impaired with the ability to read and/or create schematic diagrams. Another important item taken into account is the psychology behind how people think and learn, and in particular, how the visually impaired may differ from the sighted.

2.1 USING AND APPLYING DIAGRAMS

Diagrams and graphs model information by representing objects and relationships between these objects. These tools depict information about items such as network systems, systems management, and object-oriented analysis. Diagrams assist in visualizing information because they simplify problems and make them easier to read (Tollis, 1996). Morton (1995) also mentions the importance diagrams serve "as a documentation tool [that] represent aspects of the final product" (Morton, 1995)

Domains other than that of Computer Science also use diagrams and other graphical information because of the benefits they provide. Bromley et al (1993) use diagrams that they refer to as "Graphic Organizers" which are a "visual representation of knowledge that structures information by arranging important aspects of a concept or topic into a pattern using labels" (Bromley, K., DeVitis, L., and Modlo, M., 1999). Bromley et al (1993) state the benefits of diagrams are that they:

1. highlight key concepts and relationships which allow for critical thinking,

2. depict “connections and contradictions between existing knowledge (schemas) and new information” (Bromley et al, 1999),
3. assist one’s memory by focusing on the most important information, and
4. encourage one’s understanding of the material depicted in the diagram because the creation of the diagrams often requires one to be actively involved in creating the diagram.

Lowe (1993) claims there are three areas that need addressing when creating a diagram. The most appropriate diagram for a situation can be created by keeping the following areas in mind:

1. Provide enough detail for the intended audience (example a grade 5 student vs. a university professor).
2. Identify the instructional purpose of the diagram and fulfill only one purpose for each diagram.
3. Identify the situation(s) in which the diagram will be used. For example will it be a teacher-student environment or an isolated student.

There are various kinds of diagrams and graphical information. Blenkhorn and Evans (1998) identify five types of graphical information:

1. *Real world images,* such as photographic images, video sequences, and pictures.
2. *Maps*, including geographical maps, maps of buildings, diagrams of mechanical components, medical drawings, etc.
3. *Schematic diagrams,* which are similar to maps except they show the relationships between important objects instead of distances. Example: family tree.
4. *Charts,* which are used for reading and comparing data. Example: pie chart and histogram.
5. *Graphical user interfaces,* which include windows, icons and mouse usage.

Schematic diagrams are particularly useful in Computer Science. These diagrams often represent a structure consisting of objects and relationships between objects. In these diagrams, the relationships are more important than the actual positioning of objects (P. Blenkhorn and D. G. Evans, 1998). The diagrams do not describe detail; however, they do suggest the form in which elements will satisfy functionality of a component (McGraw-Hill, 2005).

Using Blenkhorn's and Even's (1998) classifications system, relationship diagrams would be classified as schematic diagrams. Examples of these diagrams are: directed acyclic graphs, block diagrams, flow charts, UML diagrams, family trees, organizational charts, and ER-Diagrams. Since this thesis covers ER diagrams, organizational diagrams, flow charts, and family trees, further information follows.

2.1.1 Entity Relationship (ER) Diagrams

ER-diagrams are used to represent databases and "provide a high level model for conceptual database design…" (Sumathi and Esakkirajan, 2007). These diagrams allow database designers the freedom to ignore a database's physical structure.

Sumanthi points out that ER-Diagrams have basic building blocks, which are entities, attributes and relationships. An entity is an object, for example a person. An attribute describes the entity and a relationship is an association between entities.

There are different types of ER-Diagrams. Some diagrams have distinguishing shapes for entities and their attributes. A single entity is contained within a rectangle whereas an attribute is contained within an ellipse. The attribute name is underlined if the attribute is a primary key. Lines are drawn between an entity and its attributes to denote a relationship. Relationships are contained in a diamond connected by lines to the entities. (See Figure 2.1 below)

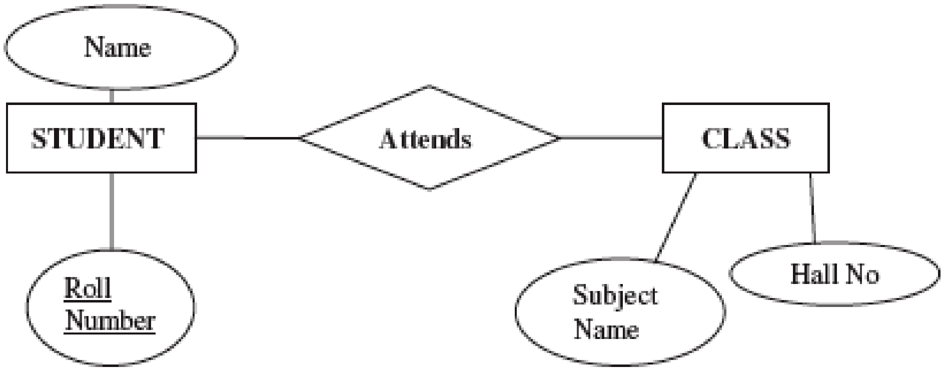


Figure 2.1 - Traditional ER-Diagram (figure taken from Sumanthi – page 33)

Other ER-Diagrams take on more of a UML approach (Connolly and Begg, 2002), which leads to a more simplified diagram. In these diagrams an entity's attributes are contained within the entity itself (See Figure 2.2 below). Relationships are only contained within a diamond, as per the traditional method, when the relationship exists between more than two entities.

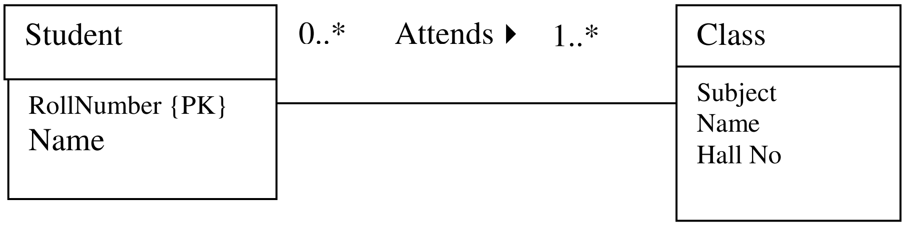


Figure 2.2 - UML influenced ER-Diagram

2.1.2 Organizational Diagrams

Organizational diagrams are a graphical representation of the internal structure of an organization (See Figure 2.3 below). For example this organization could be a company and the diagram could show the hierarchy of the organization.

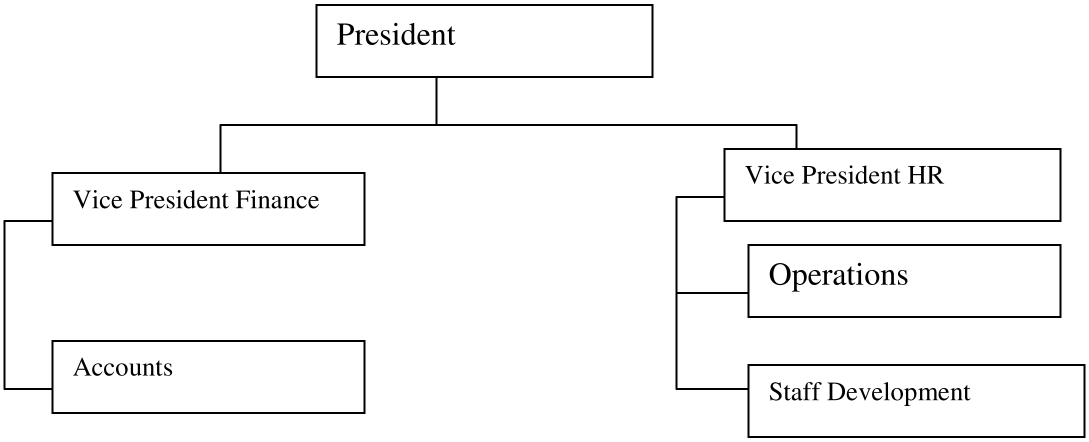
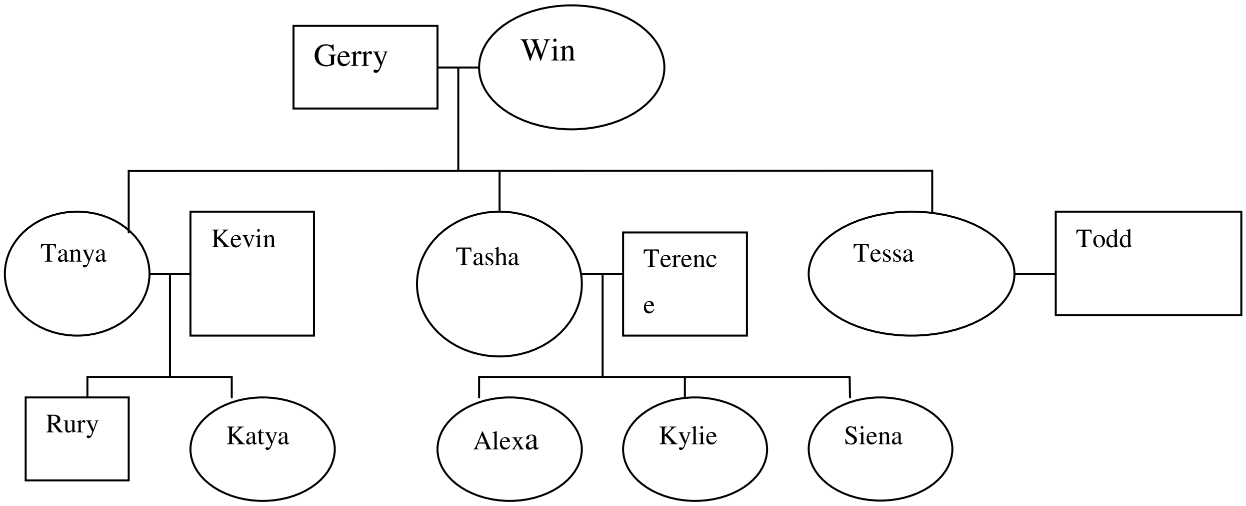


Figure 2.3 - Example of an Organizational diagram.

2.1.3 Family Trees



Family trees are a method of recording genealogical pedigrees. They depict family structures and can include information such as: birthdates, year of death, name(s), gender, marriage and divorce (See Figure 2.4 below).

Figure 2.4 - Example of a Family Tree Diagram

In this diagram females are denoted by circles and males by squares. A line between two persons indicates marriage. Lines extending from marriage lines indicate children from that marriage.

2.2 DIAGRAMMING TOOLS FOR THE SIGHTED

When it comes to creating diagrams, the sighted have an array of electronic resources. There are tools specifically for drawing and/or creating diagrams, and in some computer programming areas (ie. Databases), there are tools for project creation that include creating diagrams.

Programs specific to diagram creation require the user to manually create diagrams by dragging and dropping elements into the Graphical User Interface. There are a number of software programs for creating diagrams. Examples of diagramming software are Microsoft's Visio, ConceptDraw and OmniGraffle.

Computer Aided Software Engineering tools (CASE) are often used for project creation. . Blenkhorn and Evans defined a CASE tool as "…specialized drawing packages that have additional tools for specialized operations, such as checking the consistency of diagrams between levels" (P. Blenkhorn and D. G. Evans, 1999). Case tools can also provide support for items such as code construction, testing, report painting, user screen design tools, code reuse search facilities, automated documentation facilities, code generators, and versioning controls (Banker and Kauffman). These diagramming tools often tend to be able to create diagrams automatically based on the underlying data.

2.3 TRADITIONAL TACTILE DIAGRAMS AND ASSISTIVE TECHNOLOGY

Diagrams are highly visual and as such, diagramming tools are built with sighted users in mind. Horstmann et al. (2004) mention that "[a]ccess to diagrams is currently provided to blind people in the form of either verbal descriptions or tactile diagrams" (Horstmann et al, 2004).

Since diagrams are built for the sighted, the visually impaired must make use of specialized systems in order to access them. These systems can often be composed of assistive technologies and specialized software. To further understand the difficulties with diagrams, an investigation into traditional tactile diagrams and assistive technology follows.

2.3.1 Traditional Tactile Diagrams

The most traditional methods for presenting diagrams to the visually impaired are either by a verbal description provided by a sighted person or by providing tactical diagrams consisting of raised graphics and Braille created on swell-paper or Braille paper. Yu et al found that "Several problems are associated with this kind of graph presentation technique" (Yu, W., Ramloll, R., and Brewster, S., 2001). They state these problems as being:

1. that only 26% of blind university students have learned Braille,
2. the low resolution quality of raised graphs provide only basic diagram understanding,
3. details are difficult to perceive,
4. dynamic data is impossible, and
5. without assistance, graph exploration can be time consuming.

Furthermore, the traditional methods often require special resources (example: Braille printer) which are not always available or portable.

Aldrich and Sheppard (2001) conducted interviews with visually impaired students to understand their feelings about tactile diagrams. In general they found that students believe there are advantages of using tactile graphics over text when presenting spatial information. However, Edman (1992) notes that proportion is difficult because it causes problems with language and with graphics. Aldrich and Sheppard (2001) also suggested that an overall summary is difficult to build by touch because information is extracted sequentially. They feel that this may add to the students' frustration with diagrams yet they also think that the visually impaired may overestimate "…the ease with which sighted people can interpret graphics" (Aldrich and Sheppard, 2001).

Sheppard and Aldrich (2001) found that teachers felt that learning to read tactile diagrams is difficult. Some teachers stated that to be fully understood, diagrams need to be presented with other media such as models, descriptions, the real thing and often time consuming explanations. For this reason, diagrams are often avoided. Some teachers complained that the length of time it takes to create a tactile diagram is not always worth the effort because these diagrams usually only serve to make a small point.

2.3.1.1 Size

The actual physical size of a tactile display is often debated and is usually based around the preferences of the reader. Edman (1992) points out that there are different items to take into account. For example, small objects and images are more difficult to decipher using touch (Edman, 1992; Aldrich and Sheppard, 2001); however, they allow the most information to be taken in at one time (Edman, 1992). Whereas large objects and images allow a reader to decipher what is being read more easily (Edman, 1992). If the image is too large, it is difficult to understand the big picture of the image. (Aldrich and Sheppard, 2001)

Two different size guidelines for an entire diagram are presented by Edman (1992); one is the size of the span of one's hand (when the hand is extended it is the end of the thumb to the end of the little finger). The other is the size of two hands (extended hands with thumbs barely touching).

Regardless of the physical size, there seems to be agreement that the amount of information depicted will have an influence on the size of the diagrams. Edman (1992) and the students and teachers interviewed by Aldrich and Sheppard (Aldrich and Sheppard 2001; see also Sheppard and Aldrich 2001) agree that diagrams must be kept to the simplest form; this prevents information overload. Edman (1992) suggests using keys to explain diagram irregularities.

2.3.1.2 Layout

Although students seemed to prefer verbal descriptions over tactile diagrams, they suggested that information should be layered over more than one tactile diagram, especially when dealing with very detailed diagrams. (Aldrich and Sheppard, 2001) Edman (1992) suggests that when layering diagrams, each figure needs to be identifiable by its position in the series.

"The ideal layout should lead the reader through the maze of lines, shapes, symbols, and textures with the least amount of effort, allowing him or her to locate quickly the important information that is presented."(Edman, 1992) To further simplify diagrams, the layout, and graphic content of a diagram can be changed by doing the following:

1. relocating information to a different area,
2. fit the format of the page (change the figure from horizontal to vertical),
3. only display necessary detail,
4. when layering a diagram, make one without text and one with text,
5. eliminate perspective,
6. "Make the most important information the dominant line or area in the display" (Edman, 1992).

Contrast allows readers to determine the different elements in a diagram more easily. This in turn allows them to more easily determine their location in a diagram.(Edman, 1992) An extreme example of contrast would be dead zones (where there is no texture). Dead zones can improve symbol and Braille readability within a textured zone (Canadian Braille Authority English Braille Standards Committee, 2003). The Canadian Braille Authority English Braille Standards Committee (2003) found that squares, circles and triangles were the easiest shapes to identify.

2.3.1.3 Symbols

Aldrich and Sheppard (2001) noted that some students seem to have trouble with lines. Troubles included following the lines and lines being too close to other lines. Sheppard and Aldrich (2000) suggest keeping lines at least 2 mm apart.

The Canadian Braille Authority English Braille Standards Committee (2003) suggests that lines can be easier to follow and read when they are bold and either solid, dashed or dotted. However, lines of the same strength (thickness) are difficult to distinguish between one another and curved and diagonal lines are difficult to follow. If lines cross, it is best to have two different types of lines cross such as a solid line cross a dashed line. Aldrich and Sheppard found that teachers try to stay away from lines that cross (Sheppard and Aldrich, 2001) and recommend avoiding line drawings (Sheppard and Aldrich, 2000).

Edman (1992) explains that to make a printed display more readable in a tactile format, forms are often replaced with symbols such as circles, squares and triangles. These "coded symbols"(Edman, 1992) are used in cases where original shapes are not needed for conveying the original message. She points out that in certain cases it is important to inform the reader of this substitution. For example, if you are using symbols in the place of colour or shading. (Edman 1992). The Canadian Braille Authority English Braille Standards Committee (2003) found that the easiest shapes to identify were the square, triangle and circle when the size of the shape was .7cm or larger. They noted that the cross and star are more difficult to identify.

Textures can be difficult to differentiate when they are very small (Aldrich and Sheppard, 2001). Sheppard and Aldrich (2000) suggest that using shapes which are filled help identify whether you are feeling inside the shape. Using contrasting heights and space such as dead zones also improves readability (Canadian Braille Authority English Braille Standards Committee, 2003). However, Canadian Braille Authority English Braille Standards Committee (2003) found that for tactile polygons, "Heavy patterns, lines within shape interfered with identification" (Canadian Braille Authority English Braille Standards Committee, 2003). Instead they suggest that big patterns, such as dots and brick are preferred.

2.3.1.4 Labels

Labeling is difficult because labels can stretch across an image going further than the item the label is representing and can take up a lot of space. Labels should be placed between 2mm and 12mm away from the object they are labeling (Canadian Braille Authority English Braille Standards Committee, 2003). In order to avoid confusion between diagrams and labeling, Sheppard and Aldrich (2000) recommend avoiding label lines. When using legends, they should be placed outside the graph or diagram and appear before the graph or diagram (Canadian Braille Authority English Braille Standards Committee, 2003).

2.3.2 Assistive Technology

Cohen et al (2006) define AT as "… a general term used to describe devices or software that helps an individual provide input or receive output from the system"(Cohen, R. F., Haven, V., Lanzoni, J. A., Meacham, A., Skaff, J., and Wissell, M, 2006). There are currently many ATs available for the visually impaired. It should be mentioned that ATs are often expensive and can cost thousands of dollars.

2.3.2.1 Screen readers

Cohen et al (2006) state that "[t]he main technology that visually impaired users use to access a computer is a screen reader"(Cohen et al, 2006). Screen reader software runs behind other applications and reads text that appears on the screen. Screen readers are unable to provide context and cannot read images (unless underlying coding provides a description i.e. an alt tag). Examples of some common screen readers are JAWS, Window-bridge, and Window-eyes. Basic screen readers are now being implemented into Operating Systems such as Windows Vista and Mac OS.

2.3.2.2 Screen magnifiers

Screen magnifying software is used by visually impaired who have some sight capabilities but require text and images to be enlarged. Examples of common screen magnifier programs are Zoomtext, LunarPlus, and MAGic.

2.3.2.3 Braille printers and Embossers

Braille printers or embossers use a number of techniques to print Braille to paper. Braille can be embossed onto paper via impact (pins creating indents in the paper) or by using swell paper (paper which swells when heat is applied).

2.3.2.4 Refreshable Braille display

A Braille display can connect to a computer in order for the user to read in Braille what appears on their computer screen. The device works by raising and lowering pins to provide the Braille output. As a user moves around the screen, the display automatically updates itself. The resolution of these displays is often limited. Displays can typically display anywhere from 20 to 80 cells at one time; where a cell can represent one character.

2.3.2.5 Optical Character Recognition & Scanners

Optical Character Recognition is used by visually impaired to scan hard copies of documents to turn into digital documents. This enables the user to output the document into a more usable format such as Braille or voice. Although this technology works well for textual documents, it cannot translate images and diagrams.

2.3.2.6 Closed-Circuit Television (CCT)

A video camera projects a magnified image onto a screen. Video monitors, televisions, and computer monitors can be used as the screen.

2.4 MENTAL MODELS

Humans are visual by nature. We have art such as paintings, movies and literature. All these items traditionally require sight. A fair assumption is that someone who has never had sight probably thinks and deals with things differently than the average sighted or previously sighted individual.

Hatwell and Martinez-Sarrochi (2003) indicate that tactilely reading diagrams or drawings can be costly to a visually impaired person. They state that the visually impaired are resistant to doing things similar to the sighted, which is referred to as “visual colonization”. Regardless of the costliness of tactile images to the blind, “…the blind can benefit from the use of drawing, doubtless because of the intense cognitive work and depth of processing it imposes in order to be understood”(Hatwell & Martinez-Sarrochi, 2003).

2.4.1 Perceiving Spatial Relationships

Visuospatial perception refers to the ability to recognize and visualize spatial relationships and locations between objects. Miller (1982) states that “visual experience is neither necessary nor sufficient for spatial organization” (Miller, 1982).

Cornoldi (2000) found that “numerous studies showed that congenitally totally blind people are able to generate and process visuospatial images and in some cases, the blind can perform as well as sighted individuals” (Cornoldi, 2000). Cornoldi et al (2003) also believe that the absence of sight does not prevent processing and utilization of visuospatial mental images; however, they suspect that these images are organized differently from the sighted. Their assumption is that “this difference should be caused by the type of stimuli that elicits the creation and use of mental images.” (Cornoldi, C., Fastame, M. and Vecchi T, 2003)

In further explanation of his findings, Cornoldi (2000) presents the concepts of passive storage and active storage. Passive storage is the retention of visuospatial information while active storage is the transformation, manipulation, or integration of stored memory. He found that visually impaired individuals perform passive tasks involving visuospatial images with the same accuracy as sighted people, but had more trouble than sighted people when required to manipulate the images. This seems especially true when working with 3D images where the impairment seems to be “…the contemporary maintenance of more than one mental representation…” (Cornoldi et al, 2003). Cornoldi directly relates this problem to his findings that indicate “congenitally blind cannot have visual traces” and “cannot use traces to generate more complex mental images” (Cornoldi, 2000). This is because visual traces, a type of mental imagery, are gained only by visual experience.

Although a person does not require sight in order to create and understand spatial models, Cornoldi et al (2003) found that visually impaired persons require more time to generate mental images. This could be a result of “…blind people show[ing] a selective difficulty in processing different information simultaneously” (Cornoldi et al, 2003). Miller (1982) also found that there are deficits in blind children in comparison with the sighted blindfolded children which are “…specific to tasks that demand mental reference to external co-ordinates or to a spatial layout of configuration" (Miller, 1982). She also indicates "all mental rotation tasks that cannot be solved by using current prominent tactual features involve a heavy memory load" (Miller, 1982).

Cornoldi (2000) states that visual traces are different from generated mental images, which are gained from other information such as touch and long term memory. An example of where a visually impaired person would gain generated mental images might be in navigation through physical spaces (way-finding). Orienting in space can be easy; however, updating mental representations can be challenging. Visually impaired individuals can make use of mental imagery strategies similar to sighted individuals. Visually impaired people tend to work best within two dimensional spaces where they can perform better than the sighted in memory tasks.

2.4.2 Learning

Schneider and Strothotte (2000) suggest that it is best to use the learning-by-doing principle. They go on to explain that when visually impaired people are about to embark on an outing to a destination they have never visited before, they often memorize the layout of a given area, learn the pathway segments, and then the angles between the paths (Schneider and Strothotte, 2000).

Sanchez and Aguyo (2005) observed that blind learners rely on past experience to build their abstract thinking. Only time using their program helped users gain the necessary experience for understand the programming paradigms.

In their experimentation, Sribunruangrit et al found that "…bimodal perception improves the spatial perception ability and the memory of position during the exploration of forms" (Sribunruangrit., N., Marque, C., Lenay, C. and Gapenne, O., 2003) for blindfolded sighted individuals. To determine this they had ten blindfolded subjects explore figures, such as shapes, using a tablet and stylus in one hand and a tactile simulator array in the other hand. The tactile simulator presented tactile feedback of the figures to the user. Three exploration methods were compared; one, not having any auditory reference points; two, having auditory reference points provided by the system; and lastly, having to mark reference points for oneself. When comparing these methods it was found that users were most efficient when the system marks the reference points.

Similarly, Jeung and Gluck (2002) conducted experiments using muti-modal feedback when dealing with thematic maps. In a number of different experiments, information was provided to participants for two variables. The information was provided in one of the following combination of modes: both variables as visual information, one variable as visual and one as auditory, one as visual and one as haptic, and finally one as auditory and one as haptic. Interestingly, they found that when asked to remember information, people using multimodal display did best when the display combined auditory and haptic feedback. Some teachers interviewed by Sheppard and Aldrich (2001) found that if the students were involved in creating haptic diagrams, it increased their memory retention.

Very young sighted children and blind children with some visual experience are able to code spatial references in relation to external cues. For example, they can remember the location of an item in a room based on the location of a different item. However, Miller (1982) found that "… congenitally totally blind children tended not to use external cues as means of spatial reference [which] must clearly lead to a lack of knowledge of external spatial relations" (Miller, 1982). She mentions that the congenitally blind must be taught to use external references. She also mentions that while sighted children can view and recall items in parallel, blind access items sequentially.

In Horstmann et al's (2004) study they determined that visually impaired users could build a mental representation of hierarchical structures as well as navigate them. It was also noted "…how visually impaired users prefer to conceptualize hierarchies based upon their existing experience of navigating tree structures in programs such as Windows Explorer" (Horstmann et al, 2004). This means that they preferred to navigate information from left to right.

In Heller's (2006) work, visually impaired persons tried to identify tactile images. The subjects' performance increased when they were provided with categorical information about the pictures. Heller believes that these results may indicate "…problems accessing semantic memory, rather than intrinsic limitations in haptic picture perception..."(Heller, 2006)

When it comes to touch and the blind learner, one needs to understand the requirements placed on such a learner. Tobin et al (2003) explain that "Touch reading places much greater demands upon the learner" (Tobin, M., Greaney, J. and Hill, E., 2003) and justify this by stating that “the cognitive and perceptual demands made upon the young blind learner are significantly greater than those experienced by sighted children” (Tobin et al, 2003). For example, in the case of reading Braille, these learners must store information until the learner can interpret a whole word or phrase. This puts much strain on their short-term memory.

2.4.3 Sensing

The human has five senses; sight, sound, smell, taste, and touch. In computing environments we rely mainly on sight and sound. However, when the visionary channel is removed, one must rely on other senses. For the visually impaired sound and touch are most important. Not all visually impaired persons are completely blind, nor have they all been blind since a very young age and so limited sight and memories of sight play a role in how they use their remaining senses.

2.4.3.1 Sound

Lai and Chen (2006) conducted an interview where ‘listening to music’ was one of the most popular methods for passing time. Interview and experimental results led them to the conclusion “…that hearing is one of the most essential channel toward external messages” (Lai and Chen, 2006). As a result they suggest that further studies should be done on the interfaces between humans and audio appliances.

Miller (1982) states that in order for sounds to provide reliable feedback, they must come from fixed sources. This makes sense as Hatwell and Martinez-Sarrochi (2003) explain that “audition is specialized in the perception of successive information” (Hatwell and Martinez-Sarrochi, 2003). For this reason, sound is most useful for perceiving “temporal stimuli (duration, rhythms, speech, etc.)” (Hatwell and Martinez-Sarrochi, 2003). Sound is sequential so if the sequence is changed, the meaning can be changed.

2.4.3.2 Sight

Experiments indicated that very low vision persons performed better in haptic pattern recognition than did blindfolded sighted, cognitively blind and late blind. This may be because these individuals are able to see some motion of their hands (Heller, 2006).

The late blind seem to be at an advantage when working with tactile graphics and perform better than both blind and blindfolded sighted individuals. Hatwell & Martinez-Sarrochi (2003) indicate that this is a result of their past experiences and the intense training they receive in the tactile modality.

2.4.3.3 Touch

There are basically two parts to touch. Kinasthetic perception, which refers to forces sensed by muscles and joints and cutaneous perception, which accounts for the skin's mechanoreceptors that can pick up vibration, temperature and pain. (Brewster & Brown, Nordichi 2006)

Two-point tactile threshold felt by one's hands was another area of experimentation conducted by Lai and Chen (2006). They found that the blind's fingertips have a sharper sensation than a normal-sighted person's fingertips. They concluded "this probably has a lot to do with the fact that the blind students are accustomed to using the pulp of their index finger to read in Braille" (Lai and Chen, 2006). Heller (2006) found similar results and states that blindfolded sighted subjects are much slower and less accurate at picture matching tactile images then visually impaired subjects. However, he indicates that this could be a result of the sighted participants' unfamiliarity with viewing tactile diagrams via touch only.

Although touch can be sequential, one does not need to explore it in a linearly fashion. Spatial properties, like location and direction, can be obtained by using touch. However, one's success at achieving accurate results can be dependent on "exploratory movements and the mental synthesis achieved at the end of the perceptual process" (Hatwell and Martinez-Sarrochi, 2003). Heller (2003) also mentions that the congenitally blind are limited by touch because of their limited knowledge about spatial properties. Wall and Brewster (CHI 2006) have suggested that often tactile media, due to its spatial constraints, requires a sighted person's verbal description of a graph or image to assist a visually impaired person's exploration. (Wall and Brewster, CHI 2006). However, Ballesteros & Heller (2006) indicated that when identifying objects with touch alone, participants could be quite fast and efficient when they were allowed to use unrestricted hand movements and use all of their fingers as opposed to when restrictions are imposed on how one can explore an object.

Wall and Brewster (CHI 2006) conducted some observational studies. They found that when exploring tactile diagrams and tables, participants had a similar approach in that they would obtain a rapid overview of the diagram by feeling it with both hands. In fact, Edman (1992) states that it is important that readers be trained to use both hands for reading tactile diagrams because it involves both sides of the brain in processing information.

Wall and Brewster (CHI 2006) found that diagrams that contain Braille require much space resulting in cluttered diagrams and tables. For this reason tables could not be preserved in their original layout making it difficult to communicate with sighted persons.

When it comes to reading Braille, a reader must have fine motor control such that they can scan smoothly through each line of Braille. This also means that “[t]he perceptual window, the width of the human finger, is narrower in touch than in vision” (Tobin et al, 2003)

Heller (2003) explains that illusions exist for both vision and for touch. Illusions as they apply to touch can include items such as “movement where no real motion over the skin exists”(Heller, 2003); “distortions in judgments of extent, or in curvature”(Heller, 2003); “ a doubling of sensations that occurs when crossed fingers contact a single curved object”. There is also the size-weight illusion (the weight of an object is overestimated in smaller objects). Heller (2003) eludes that when investigating images or objects via haptics, since the right brain is better for making accurate spatial judgments, then investigations should be done using the left hand in order to avoid spatial errors. He also indicates that non-optimal haptic exploration, such as using whole arm motion, of items could lead to these misperceptions (Heller, 2003). However, these illusions are dependent on the size and scale of the stimuli. For example, illusions may disappear if the stimulus is small enough and within scale of the hand.

Through interviews and a focus group, Wall and Brewster (CHI 2006) identified current techniques and tools used for exploring diagrams. From these investigations they came up with a set of guidelines.

1. Promote non-sequential exploration of data by allowing investigations using 2 hands.
2. Provide easily attainable and distinguishable reference points.
3. Allow alternate memory aids. Example: highlighting items in some way.

4. Preserve visual aspects to allow for communicating and collaborating with sighted persons.

Douglas and Willson (2007) conducted experiments where they compared the use of 3D tactile graphs and graphs which used vibrations displayed by a Phantom. They found that the magnitude had a natural mapping onto amplitude because participants consistently made this mapping. They also found that exploration of their haptic model of a visual graph required increased contact time in comparison to the graphs displayed using vibrations. They believe this is due to it requiring a greater cognitive load.

2.5 RELATED WORK ON DIAGRAMMING TOOLS FOR THE VISUALLY IMPAIRED

Different subject areas require different types of diagrams. If we look at the area of software development for example, we see that there are existing tools which software developers already utilize. Some of these development applications allow the ability to create visual diagram images pertaining to the project in development. A simple example of this is the ER-Diagramming feature available in MS Access. However, these tools are often unfriendly to the visually impaired. For example, on the American Foundation for the Blind website, one programmer talks about his encounters with certain developer tools. He complains that the "… Visual FoxPro development environment was nearly impossible to use with a screen reader" (The Right (or Required) Tool for the job, 2008). He goes on to talk about how "[Visual Fox Pro] lacked keyboard access to some features, used nonstandard controls, and some text was invisible to some screen readers" (The Right (or Required) Tool for the job, 2008). This programmer complained about Visual Basic 6.0, indicating icons in the toolbox are invisible to most screen readers. The only screen reader able to handle the toolbox was Window Bridge and it could only read the default set of icons. Otherwise, visually impaired users must use "help" for each icon before they can determine the icon they are on.

Kamel and Landay (2000) explain that "[b]lind users have had only limited success in using drawing programs because traditional drawing software lacks the capability to translate graphical data output in a way that screen access programs can interpret"(Kamel and Landay, 2000). They go on to say that in their paper, “Millar showed the importance of visual feedback in a study comparing the ability of congenitally blind and sighted but blindfolded children to draw the human figure”(Kamel and Landay, 2000). Kamel and Landay (2000) also state, as suggested by Millar, that detail provided in these drawings was directly related to visual feedback. It was also mentioned that “[s]ighted but blindfolded children performed only slightly better than congenitally blind children in creating details, cohesion, and alignment” (Kamel and Landay, 2000).

In their research, Horstmann et al (2004) identify three different types of diagramming techniques for the blind. These techniques are:

1. Tactile diagrams combined with touchpad technology “… are sometimes referred to as audio-tactile diagrams”(Horstmann et a, 2004l). This involves placing a tactile diagram onto a touchpad. When the diagram is touched, auditory feedback is provided.
2. Combining refreshable displays with sound.
3. Translating visual images to auditory images “for example using the pitch and timbre of different musical instruments to indicate different aspects of the image” (Horstmann et al, 2004).

A fourth technique exists, which involves using a force-feedback pen called a PHANTOM to investigate virtual diagrams.

Upon examining the research, three types of existing systems related to reading and creating diagrams for the blind emerge. These three categories are Diagram Translation Systems, Drawing Systems and Diagram Creation and Translation systems.

2.5.1 Diagram Translator Systems

Wall and Brewster (CHI 2006) introduced the VTPlayer Tacticle mouse to the individuals they were interviewing. This mouse has 2 sets of 4 x 4 pins which rise and fall as the mouse is moved over an image. Each pin represents a pixel on the screen where a dark pixel is represented by a raised pin and a light pixel is represented by a lowered pin. The user can place one finger over each set of pins. The intent of the mouse is to present graphical information. They found that the participants often confused this output medium with Braille, didn’t hold the mouse traditionally (2 hands instead of one), and were disappointed by the small display and low resolution of the device (Wall and Brewster, CHI 2006).

AudioGraf (Kennel, 1996) investigated the use of a touch panel in conjunction with auditory feedback. Visually impaired users interact with the system by touching the panel to select parts of a diagram. Each selection is displayed to the user aurally. For example, a connection sounds like a plucked string and text is verbalized. Although users were able to read the diagrams, users sifted through an excess of information because everything is explained in extensive detail.

The solution to the above mentioned problems was Tac-tiles (Wall and Brewster, NordiCHI 2006), a system that uses a combination of tactiles and audio in order to represent pie charts, bar charts and line graphs. They use an overlay on a touchpad to allow the user to easily orient themselves. These overlays are independent of the data such that they can be used with any pie chart. The user can provide input to the system and browse the graphs by using a stylus with their dominant hand. They are provided with feedback from this system by using a haptic mouse which they hold in their non-dominant hand, as well as speech and non-speech sounds. However, testing revealed that users felt the haptic information from the mouse was redundant to the non-speech elements of the system. Perhaps for this reason, users often forgot to use the haptic mouse. Users also had problems using the stylus for navigation.

AUDIOGRAPH (Alty and Rigas, 1998) is a system that provides a visual output for the sighted and a completely audio output for the visually impaired. Output and input feedback are provided solely in the form of music. Using the keyboard, users can navigate about a diagram which is displayed on a 40 x 40 grid. Different musical cues represent items such as size, shape and location of objects.

TACTIS is another touchpad system. It combines tactile overlays, tones and speech to create a user interface with which to explore maps, diagrams and images (Gallagher and Frasch, 1998). Users can explore the diagrams on the touchpad where a light touch reveals a tonal value and increased pressure reveals further information via speech. Since "…visually impaired people find that tactile information alone is not enough for interpretation of a graphic image" (Gallagher and Frasch, 1998), TACTISs combination of speech, tactile and tones seem to provide information to the users well. However, users must print out each tactile overlay before they can explore a graphic. As well, the system does not easily facilitate creating ones own diagrams without the assistance of a sighted individual.

iGraph-Lite(Ferres, L., Verkhogliad, P., and Boucher, L, 2007; also see Ferres et al, ASSETS 2007) focuses on making graphics accessible in Statistics Canada's publication "The Daily". The project focuses on generating summaries of graphical data and exploring data by the use of sound. The project provides interaction with the use of natural language. Users can navigate and explore data otherwise represented in graphical format only. Graphics are input into the system as XML files. In this case most XML files are an export from a MS Excel document. The XML is analyzed and input into the navigator which generates natural language to describe the graphs. However, the reliance on natural language and the simplistic command structure make it difficult for the user to customize.

TeDUB (Horstmann et al, 2004) describes diagrams and focuses on Unified Modeling Language (UML) diagrams. The diagram descriptions are based on guidelines presented by the Confederation of Transcribed Information Services (COTIS). Bitmap images or text-based electronic data format are acceptable input methods. Users navigate via keyboard or joystick. This solution allows collaboration between sighted and non-sighted users. Another strength is the flexibility of the system; users create their own methods for examining diagrams. There are some downfalls such that "[t]he image analysis stage is prone to errors that can lead to inaccurate interpretation and failure to identify important image components"(Horstmann et al, 2004). Their solution involves sighted users supervising and intervening when needed, which removes independence from the visually impaired user.

Metatla, Bryan-Kinns, and Stockman (2007) created a system for reviewing UML Class Diagrams. Their approach was to compare verbal and nonverbal modes for the speed one could navigate a diagram and comprehensibility of the diagram. By using keyboard commands, users were able to obtain greater detail about components of the diagram. Metaltla et al (2007) found that their consistent diagram decomposition allowed users to successfully anticipate the location of information that they needed. Non-verbal feedback provided the user with enough information to determine whether their intended action was the actual action.

Yu et al (2001) produce a system using the PHANToM feed back device to simulate an embossed line graph. They found that “The PHANToM has been proved to be good at providing kinesthetic rather than cutaneous sensation. The single point contact provided by PHANToM is inadequate when used on embossed line graph objects.” (Yu et al, 2001) They also found that users were not able to perceive an accurate perception of the line graphs because of the combination of the device and the modeling technique they used.

Using a PHANToM, McGookin and Brewster (2006) allow one to explore bar graphs by using one of two views. Users can navigate a bar graph tactily (bars feel as though they are engraved) or they may use a “sound bar” for a quick overview of the graph (where the height of a bar is represented as a tone). While McGookin and Brewster (2006) found that the sound bar worked well for speeding up users’ response times for answering questions about a specific bar graph, they found that users still had problems with exploring the bar graphs tactily. As well, this solution is currently limited to bar graphs.

2.5.2 Drawing Systems

Some drawing solutions involve touchpads combined with tactile images. Kamel and Landay (2000) explain “this requires the user to purchase a tablet, possibly a prohibitive expense” (Kamel and Landay, 2000). Instead, they use electronic images making images easier to modify. The Integrated Communication to Draw (IC2D) (Kamel and Landay, 2000) tool uses grids to provide visual element locations. A keyboard provides input and output is provided aurally. Users draw images in a 3x3 recursive grid. A recursive grid refers to the ability to subdivide a cell into another 3x3 grid up to an additional two levels; providing up to a 27x27 grid. Kamel and Landay (2000) found that levels beyond 27x27 become too difficult to conceptualize. Locations on the grid are presented in the form of a telephone keypad because blind individuals are trained on the use of a telephone keypad in school. Users specify their own labels for objects and positioning. Although it gives users a more precise, feedback oriented drawing system, it is time consuming and not diagram specific.

2.5.3 Diagram Creation and Translation Systems

PLUMB (Calder, Cohen, Lanzoni, Landry and Skaff, 2007; see also Cohen et al, ASSETS 2007; Cohen et al, SIGCSE 2007; Cohen, Yu and Skaff, 2005) is one of the few tools that supports both reading and creating graphs. Their focus is on "communication of graphs and relational information to blind computer science students" (Cohen et al 2005). Graphs are displayed on the tablet PC, and with the help of auditory cues, blind users navigate graphs using either the tablet and pen and/or a keyboard. Calder et al (2007) mention "[t]he downside is that exploration can be slow and depends on the precision of the user's hand movements" (Cohen, 2005). As a result, it is "…difficult to get information about incident graph elements since the user needs to move the pen around the area and wait for sound notification" (Cohen, 2005).

PLUMB uses XML documents with the Graphics eXchange Language (GXL) to create graphs. Users create graphics via the command line or with second party GXL supported programs. Unfortunately, the paper does not provide information regarding feedback during diagram creation.

Kurze created Tdraw (Kurze, 1996), which places heat-sensitive swell paper onto a Thermostifft digitizing tablet. Input is recognized as users draw on the swell paper and provide appropriate voice commands. Users connect attributes to the elements they are drawing by providing verbal commands. Once a drawing has been completed, a tablet and special pen can be used to explore. The computer recognizes when the pen approaches an element and provides text-to-speech output to the user. Unfortunately, the swell paper means that drawings cannot be fully altered later. As well, there is no feedback provided to the user during the drawing process. This makes it difficult to draw items in relation to one another, for example, two shapes of equal size.

In their work, Minagawa, Ohnishi and Sugi (1996) created a system on a refreshable display such that users can create and explore diagrams and images haptically and aurally. The system is based on an 8x8 pin display. Each pin in the diagram can be mapped to aural data. To create a diagram, using Minagawa et al's (1996) work, users must set the level for each pin and associate any aural data with the pin. Requiring the user to manually set the levels for each pin is somewhat of an arduous task. It is also difficult for the users to create images that are readable by others without obtaining an explanation from the artist.

Blenkhorn and Evens (1998) created a CASE tool that they refer to as Kevin. By using the CASE Data Interchange Format (CDIF), Kevin is able to read, and modify diagrams from other CASE tools. Unfortunately, Kevin does not provide layout formatting and it relies on exporting data to other CASE tools in order to create the visual diagram. They use an N2 chart which is a type of software engineering table for mapping a Data Flow Diagram (DFD) to a tabular format. They print the N2 Chart as a tactile diagram and overlay it on a touchpad. There are a series of buttons to carry out CASE tool operations. Each button uses a 'hapticon' or a tactile icon to indicate the resulting function. Users can also use the keyboard to name transformations and data flow. Informal evaluation showed that a Braille reader was easily able to use the system while a non-Braille user abandoned in frustration. The Braille reader was able to read "a complex model with more than 12 DFDs that had around 60 transformations and 180 connections" (Blenkhorn and Evens 1998).

Kevin has 44 buttons so it is not reasonable to expect a user to be able to memorize the location of all the buttons. Users found it both cumbersome to navigate the number of buttons as well as awkward to determine the centre of the table cells.

Yu et al (2003) created a web tool that could handle simple graph generation and allowed for interactive drawing. The automatic generation was similar to Microsoft Excel's graph-plotting tool. By using the WingMan FF mouse in conjunction with audio, users were able to explore the resulting graph. Users were able to manually draw graphs by using the interactive drawing tool. By using the keyboard or the WingMan mouse, users can navigate a virtual grid and define locations on the grid for drawing. They receive feedback in tactile form from the mouse as well as speech and non-speech audio to assist them in determining the cursor location on the grid. Users are able to draw up to two lines on the graph. Finished diagrams can be printed (visually or tactily) or explored with the WingMan FF mouse or keyboard. (Yu et al, 2003)

A system currently existing on the market is ViewPlus' IVEO. This system allows the user to create or modify a diagram with annotations at specific locations. When a tactile image of this diagram is printed out, it can then be placed on a touchpad. When points on the tactile diagram are pressed, the annotations are read to the user. Unfortunately, creating the images is difficult for an unsighted user and the process of creating the annotations can be slow. As well, the calibration to synchronize the tactile image and the touchpad can be difficult to achieve (Fitzpatrick and McMullen, 2008). This system also requires that the user has some method of acquiring the tactile diagrams; whether they print them out with their own hardware or obtain it from another source. The advantage of this system is that the images are saved in Scalable Vector Graphic (SVG) format. This is a markup language which allows images to be drawn such that they are scalable. This is advantageous because images and diagrams could be created by other drawing programs that support this format and then imported into IVEO's system.

Digitizer Audio Graphs is a system being developed by Choi and Walker (2010). Their first tests were on a line graph that appears on a contrasting background. This could be an image or wikki sticks (wax-covered strings that stick to each other and smooth surface and can be used to form line graphs). Users place the image on a table beneath a webcam. The image is digitized by placing data points in a Comma-Separated Values (CSV) file. Output is handled by their existing system called the Sonification Sandbox Project (SSP)(Sandbox Sonification). This system is able to map data points to different auditory dimensions and can convert the dataset into an image file. Both visually impaired and sighted users tested the system. They found that both groups understood the graphs from the auditory output and felt that what they heard matched what they produced. The visually impaired users found that "the lack of context information (e.g., axes,origin, tick marks) led to difficulty in figuring out detailed information such as the difference between two adjacent data points, slope, and point estimation" (Choi and Walker, 2010).

2.6 RELATED WORK ON SYSTEM INTERACTION METHODS

Vanderheiden and Henry (2001) suggest that one should increase the number of supported users by supporting assistive technologies. They claim that the "[k]ey to achieving everyone interfaces is the provision of all basic information in either a modality-independent or a modality-parallel (flex-modal) form"(Vanderheiden and Henry, 2001). Modality-independent refers to information stored in a format not specific to any one mode of presentation (visual, auditory or tactile). Vanderheiden and Henry recommend ASCII text because it can be easily presented in all three modalities. Modality-parallel refers to providing multiple modalities, which can work together or separately.

2.6.1 Input

As mentioned earlier, visually impaired persons learn by building on their previous capabilities and experiences. Combining the aforementioned mental model with Vanderhieden and Henry's (2001) suggestion about modality-independent and modality-parallel, we can see that there are four popular input methods; keyboard, voice, forced feedback device and touchpad with tactile overlay. A system can work functionally with the use of keyboard or voice input for the majority of visually impaired users. A touchpad on its own, however, doesn't provide the same capabilities. Touchpads will be discussed later as they are both a source of input and a source of output. This section will also touch on lesser-used input methods as mentioned in related research such as the VTMouse and joystick.

2.6.1.1 Keyboard

Wall and Brewster's (CHI 2006) interviews with visually impaired computer users identified the common complaint that extensive use of shortcut keys requires a heavy memory load. They suggest avoiding using shortcut keys when designing applications where the keyboard is a source of input. This suggestion is made because "Many users will already be employing a screen reader that relies extensively on the keyboard for navigation" (Wall and Brewster, CHI 2006).

In many systems (Yue et al, 2003; see also Horstmann et al, 2004; Blenkhorn and Evans, 1998; Kamel and Landay, 2000) it was found that users either preferred the keyboard to other input device options and/or they found the keyboard easy to use. For example, in testing their system where either a keyboard or a forced feedback mouse was used as input devices, Yu et al found that the users preferred using the keyboard because they found it faster and more natural to use. However, the resulting error rates between the two devices were similar. (Yu et al, 2003).

2.6.1.2 Voice

Chen and Tremaine (2005) conducted experiments to determine users' preferences between using voice and touchpad input. They tested 14 sighted users; however, these users were only provided with auditory output. The results indicated that while the touchpad allowed virtual information to be presented tangibly allowing additional assistance for navigation, the speech input allowed direct access to system functions. The two together were complementary as one could simultaneously navigate using the touchpad and provide the system with commands via voice. This helped improve users' task performance by reducing cognitive work load.

In Christian, Kuloes, Shneiderman, and Youssef's (2000) work, they compared times between navigating web pages with the use of a mouse or navigating via voice commands. To do these experiments they used a voice browser called Conversa. Initial experiments showed that initial times were twice as long to navigate via voice commands. They also tested two types of links on these web pages, one where they used numbers to define each link and another where they simply used the text. They found that the numbered links took longer to use when using voice commands. They hypothesize that this is because the user must first determine which number corresponds to the link they want to follow before they can start to issue the command. Christian, Kuloes, Shneiderman, and Youssef's (2000) noted that issuing voice commands requires cognitive overhead because voice commands require the user to perform the extra step of formulating the command to be spoken.

One of the problems with Conversa that surfaced was the matter of dealing with giving the system voice commands but at the same time having a side conversation. Also, the browser was most effective when the user had no accent or only a very slight accent. Lastly, the method for entering URLs was difficult as it required the user to use a military system (alpha, bravo…) for entering each letter of the URL.

Christian et al (2000) make the recommendations that when designing for voice browsing, links should be textual, not numbered, and these links should be short English words that are easily pronounced. One should stay away from similar sounding links that appear on the same page.

Many studies agree that voice, when combined with another input method for the appropriate task, achieves the best results (low error rates, low task time completion) (Christian et al, 2000; see also Van Buskirk and LaLomia, 1995 ;Grasso and Finin, 1997 ; and Schapira and Sharma, 2001).

When using voice commands, Leopold and Ambler (1997) found that three guidelines should be followed. These guidelines are:

1. Each command should have a consistent method of being said,
2. Vocabulary variations should be limited. Example: “allow either gray or grayish, but not both” (Leopold and Ambler, 1997).
3. Avoid monosyllabic commands as they can disappear into regular speech (Leopold and Ambler, 1997).

2.6.1.3 Refreshable Pin Display

Wall & Brewster observed that when using a VTMouse without visual feedback, the mouse was often unintentionally moved, such as lifting it or rotating it. These movements were un-noticed by the users and contributed to the problems the users had using the mouse (Wall and Brewster, NordiCHI 2006).

Jansson and Pedersen (2005) found problems in his work when it came to the use of a VTPlayer haptic mouse for input. He found that it was difficult to use a mouse without visual information regarding the location of the pointer and the location of the goal. He also suggests that moving a mouse in relation to a virtual map is difficult because the location relationships are not one-to-one. This is complicated even further because the mouse must often be repositioned or can be positioned unintentionally. Jansson and Pedersen (2005) believe that the visually impaired experience problems using a mouse because users may unintentionally rotate the device without noticing. As a result, the movements of the cursor are different from what the user is expecting.

2.6.1.4 Touchpads and Touchscreens

McGookin, Brewster and Jiang (2008) investigated the use of touchscreens by the visually impaired. To conduct their experiments, they used a PDA with a touchscreen and created an

MP3 player program to run on the device. They compared two methods of input. The first method used a tactile overlay on the touchpad. The overlay was comprised of five buttons (play/pause, increase volume, decrease volume, previous and next). The second method was composed of using gestures to signify the same commands. To play or pause the MP3 player one would tap the screen. To increase the volume, one drags one's finger from the bottom of the screen to the top. The opposite is done for decreasing volume. To go to the next track, one drags one's finger from the left to the right of the screen. The opposite movement is used for obtaining the previous track.

Although the subjects tested were mainly blindfolded sighted participants, McGookin et al's (2008) findings indicated that the overlay input system was significantly faster than the gesture system. The majority of problems stemmed from the system misinterpreting the gestures. In most cases, the system would mistake a command for the pause/play gesture. There also lies the problem of being able to teach a visually impaired person the gestures, especially in a system like an MP3 player, where the visually impaired person would usually receive no formal training. Most users, including the one visually-impaired user, preferred using the overlay input method. In the overlay method, it was possible to unintentionally activate a command. The visually-impaired participant suggested using an indented button system overlay instead.

Cohen, Meacham and Skaff (2006) chose to use a tablet PC because they felt that using the unit with a pen-based input device was successful for exploring geometric shapes. They also felt the compact size, the availability, and the multimedia capability make this device accessible for visually impaired persons. They also found that when traversing graphs, narrow long edges were more difficult to follow than wider shorter edges. They and others concluded, however, that the stylus was difficult to use (Cohen et al, 2006; see also Wall and Brewster, NordiCHI 2006).

An Iveo touchpad and brail printer were used by Paladugu, Wang and Li (2010) to create audio-tactile maps for visually impaired users to navigate. Using the touchpad, users were able to explore the map. More information was provided by pressing the information button located at the top right hand corner of the map. The system could provide information such as the location of the start and end points. Paladugu et al (2010) experimented with different patterns for the start and end locations on the map. Their findings indicated that users wanted different patterns for the start and end location. The users favoured patterns that were simple and easy to distinguish, a circle for the start position and a square for the end point.

2.6.1.5 Joystick

While TeDUB (Horstmann et al, 2004) was the only system to use a joystick for navigational purposes, Horstmann et al. (2004) did not report any large problems with using the device. However, it was suggested that this would not be the technique of choice by users because they only rated a mean of 3.5/5 for ease of use. Horstmann et al. (2004) also suggest that they will be implementing a feature for using the numeric keypad to replace joystick movements.

2.6.1.6 Forced Feedback Devices

Regardless of whether one uses a Phantom as an input or an output, the general disadvantages are that extended use can be quite tiring and the device takes some time to get used to. Input can be provided by buttons on the Phantom's stylus and by moving the stylus through 6 degrees of freedom. Work with forced feedback devices has been mostly concerned with providing the user with a method of output. For example, to provide input, some systems which use the Phantom require you to input commands via the keyboard (Van Scoy et al, 1999)

2.6.2 Output

The outputs available to the visually impaired are audio and tactile. Audio can be provided as speech output or a number of variously mapped sounds. Since auditory output is the most common method for receiving output, this is one medium that must be supported. Tactilely, users can access Braille displays, Braille printers, forced feedback device and touchpads with tactile overlays.

2.6.2.1 Touchpads with Tactile Overlays

A touchpad requires the user to have some knowledge and context about a system before using it. It is easy to hypothesize that the reasoning behind PLUMB's (Cohen et al, 2005; see also Calder et al, 2007; Cohen et al, Access 2006; Cohen et al, SIGCSE, 2006) slow diagram exploration times is due to the following reasons:

1. Users with no diagram experience would have difficulty when first trying to understand a diagram.

2. Touchpads do not provide tactile feedback making it easy for a user to become disoriented.

3. It difficult to locate and relocate specific parts of drawings on a touchpad. Without sight, one can only use some method of estimation to determine exact locations.

Using a tactile overlay helps alleviate most, if not all, of the above mentioned problems. However, since not all visually impaired users are familiar with Braille and tactile diagrams, the design of these tactile overlays will need to be generic. As users will probably require training in order to recognize certain elements, it is the recommendation of this author to provide all information at least aurally. Since multi-modal interaction achieves the best memory results, it would be beneficial to provide tactile feedback as a secondary channel.

2.6.2.2 Visual

Although the visually impaired suffer from vision loss, not all visually impaired have lost all sight. Patomaki, Raisamo, Salo, Pasto and Hippula (2004) in their creation of multimodal applications for visually impaired children found that the children who had some sight were constantly looking for items to look at from their surroundings while they were working with the application. As a result, Patomaki et al (2004) suggest including visual feedback so that the user can benefit from it.

2.6.2.3 Refreshable Pin Displays

Wall and Brewster (CHI 2006) found that using the VTPlayer Mouse, even for only the refreshable pin display output was difficult for the users. The VTPlayer Mouse was unable to relay sufficient information to the user because the pin arrays were too small and the resolution of the pins was not detailed enough.

Ballenger (1979) suggests that Braille has restricted message input because one can only read one character at a time. In this manner "…there is no peripheral view to aid in scanning" (Ballenger, 1979). He also explains that this method has higher demand on one's short term memory because symbols must be remembered to construct words and then words must be remembered in order to construct sentences at which point the user can finally construct the complete message. However, there is the advantage of this medium being permanent and allowing some “referability” (Ballenger, 1979).

2.6.2.4 Sound

Wall and Brewster (CHI 2006) found that it was important to incorporate audio with tactile representations. However, they caution that audio should not “clutter the tactile representation” (Wall and Brewster, CHI 2006). They also suggest that “non-speech information is better at providing an overview of the data, as it can be delivered in a shorter time than synthetic speech” (Wall and Brewster, NordiCHI 2006). One common strategy is to encode data using the pitch of a MIDI note (Wall and Brewster, NordiCHI 2006).

Kamel, Roth and Sinha (2001) created a system they call GUESS. The system presents images composed of graphical shapes to the visually impaired via 2 dimensional audio. Users can explore the images using a tablet and pen. They found that their most successful implementation of GUESS involved using a grid-based model. By using the 3x3 grid based on the telephone keypad, they assigned different musical instruments to vertical and horizontal axes. Cell boundaries were denoted by consecutively playing two different notes and the center cell was denoted by a distinctive sound. A user is able to locate shapes when the stylus touches its corresponding area. Kamel et al (2001) concluded that spatial information should be provided in auditory interfaces. Landmarks that are easy to interpret should be used to help identify target areas. (Kamel et al, 2001)

Mereu and Kazman (1996) performed experiments to determine the results of sound when assisting with visual targeting and using sound solely to pinpoint a location in a three dimensional space. Initial testing was performed on sighted users. They compared the following four environments: an environment with no audio feedback, an environment with audio that altered a sine wave, an environment with audio feedback that altered a piece of music, and an environment which used different orchestral arrangements. The best results (speed, accuracy) were obtained from the tonal environment and they found that with practice, one’s speed improves when attending to the audio cues.

When performing the same tests on visually-impaired (minus the visual environment), Mereu and Kazman (1996) found that these users "… can use the sound environments to perceive depth and position in a 3D application". Obviously a visually impaired person's time to find a position is longer than that of a sighted user with a visual display; however, the accuracy of the visually impaired when using the tonal sound was similar to that of a sighted user.

Interestingly, the visually impaired users preferred the tonal sound. Mereu and Kazman (1996) hypothesize that this could be due to the fact that the visually impaired are relying on the sound as the soul source of output. For them, the sound needs to be most accurate and the least distracting. They also made the observation that persistent audio feedback is annoying for users. They suggest that in order to guarantee a product is useable, it needs to minimize annoyances.

Edwards (1988) carried out experiments with sound navigation in a two dimensional space. In his experiments he found that most users ignored pitch. While the users did not use the tones to assist in their navigation, they did not find the tones to be a disadvantage either. The only user who did not seem to ignore the pitch information was a participant with a background in music. This participant was able to locate objects in the two dimensional space by listening for a particular tone associated with the object.

In their work, Metatla et al (2007) focused on hierarchical design using sound mappings to communicate any navigational action performed. However, they did find that by substituting the verbal descriptions with the non-verbal sounds, users' performance times increased without a decrease in comprehension.

Sonic grid, an auditory interface for assisting visually-impaired use GUIs, was created by Jagdish, Sawhney, Gupta and Nagia (2008). They used stereo to denote horizontal movement on the screen. This was done by increasing the volume in the earphone that was on the side being traveled to and by decreasing the volume in the opposite earphone. Vertical movement was depicted by using frequency, where at the bottom of the screen was the lowest frequency and at the top is the highest frequency. During observations, Jagdish et al. (2008) found that in order to provide a better representation of the screen, there was the need to play audio alerts when a user moved quickly over an object. Once hovering over an object, the system should provide further feedback in the form of speech. They also suggest that as one moves away, the amplitude of this feedback could decrease. (Jagdish et al., 2008)

Walker and Mauney (2010) looked at the sonification of datasets in much of their research for their tool Sonification Sandbox. Their previous testing had only been performed with sighted undergraduates. However, they more recently decided that their work could extend to visually impaired and so began new testing of their tool with visually impaired participants. They tested the following three stimulus sets: frequency, tempo and modulation index. Upon hearing sounds produced by altering one set of stimuli, users estimated the magnitude of the temperature, pressure, velocity, size, and number of dollars that the sounds seemed to represent. They compared the data obtained from their previous testing of sighted users against the new data obtained from blind users. Interesting findings included sighted individuals exhibiting more split polarities (example: mapping of a high frequency to high temp vs. low frequency to high temp); and blind and sighted individuals responding oppositely to dollar mappings. Since people interpreted the sonification differently, it is important to either design to your audience or provide appropriate instruction (Walker and Mauney, 2010). Differences were found between sighted, late onset blindness and early onset blindness.

Jeon, Gupta, Davidson and Walker (2010)l investigated the use of menus. They were specifically interested in unavailable menu items (ie: items that are grayed out in a menu). In their study, they found that the best results (speed and user subjectivity) were achieved when unavailable menu items were distinguished by being spoken in a whisper. This method was superior to speaking the word “unavailable” after such items or by skipping the items in the menu completely. This is because the whisper method was more efficient and it did not prevent users from creating an accurate layout of the menu structure.

On their work with AUDIOGRAPH, Alty and Rigas (1998) developed advice for creating audio interfaces. They have three different levels.

1. Detectable Musical mapping; musical structures such as pitch, rhythm, and timbre must be allocated to domain structures. Each musical structure must be distinguishable because multiple musical messages can be provided at one time.
2. Creating perceptual Context; the user interprets individual structures based on their expectations. These expectations must be created to assist interpretation.

3. The reasoning and symantic level; users are able to construct higher level structures without further training (Alty and Rigas, 1998).

Alty and Rigas (1998) also believe that the main information to be conveyed in an audio-diagram is:

1. the size of a coordinate
2. X coordinates
3. Y coordinates
4. different graphical shapes, and
5. different control actions

2.6.2.5 Forced feed back devices

Possibly one of the most popular forced feedback devices is the PHANToM. Researchers have identified general problems associated with the Phantom. These problems are: the PHANToM is a kinesthetic device (Brewster and Brown, 2005) which can only provide force on the users' fingertips. This results in a reduction in the amount of information which can be received haptically (Yu et al, 2001; see also Brewster and Wall, NordiCHI 2006, Iwata, Yano, Nakaizumi and Kawamura, 2001). The PHANToM has difficulty reproducing textures because of the single point of contact (Yu et al). For example: gridlines, often found in graphs, are difficult to produce so that they do not distract from the datalines (Yu et al, 2001). As well, shape perception is slow and memory intensive (Wall & Brewster, NordiCHI 2006).

Exoskeletons are attached with velcro bands to fingers to allow force to be applied to more of the hand. Iwata et al stated an important problem with force feedback devices, such as an exoskeleton, is that "…these devices cannot recreate a natural interaction sensation when compared to manual manipulation in the real world." (Iwata et al, 2001)

Yu et al (2003) worked with the WingMan Force Feedback mouse. They found that the limitations of the mouse were the small workspace and the weak force which only provided two degrees of freedom. Although performance could be increased with the addition of audio feedback, they found that these limitations also affected performance on resulting systems. They state that the WingMan FF Mouse is: "only suitable for 2D representations; very small workspace; limited amount of force feedback"; and a "single point contact." They also noted that mouse rotation could be confusing without the effect on the cursor position. Perhaps the largest problem with this particular device is that it has been discontinued and so it is only supported in Windows 2000 and XP (Yu et al, 2003 IEEE).

One tool that can be used to assist users and limit the amount of space taken up by objects is Tactons. Tactons are a haptic form of an icon that use vibrations in order to provide output to a user. They have the ability to use less space and time than Braille in order to provide output (Brewster and Brown, 2005). Information is encoded such that it can be retrieved using cutaneous perception. Compound messages can be formed by combining Tactons. Brewster and Brown (2005) provide the example of 'create file', in which basic elements can combine to create a simple language, which can provide feedback in a user interface.

For creating interfaces with forced feedback devices, researchers offer the following suggestions:

1. The user should be able to quickly orient himself or herself (Wall and Brewster, CHI 2006). Navigation should be facilitated by "well defined and easy-to-find reference points" (Sjostrom, 2001; see also Wall and Brewster, CHI 2006) and the reference system should not change. For example, buttons, even though disabled, can still act as a reference point.

2. By providing the user with a search tool, there is a reduction in missing objects and determining whether the object actually exists. The tool could be like a path between objects or it could be like a magnet.

3. When the haptics are not required to feel like something real, a system can be made easier to navigate by creating attractive force and by refraining from the use of sharp corners(Sjostrom, IEEE 2001; see also Bussell, 2003) and by using recessed rather than raised lines (Bussell, 2003). Allowing the system to play back the trajectory a user just followed (trajectory playback) can assist the user in being able to perceive shapes. The playback speed should be adjustable so that users can slow it down when more time is needed to recognize an object (Crossan and Brewster, 2008).

4. Thin walls are too easy to pass right through. Instead, think of replacing these walls "…with a magnetic line that pulls the user to the center of the area." (Sjostrom, IEEE 2001).

5. Different manipulandum, or tools users grasp in their hands, affect haptic sensations differently because of the manipulandum's form and surface. Manipulandum can affect how force is applied, a user's movements, and how objects feel. (Sjostrom, IEEE 2001)

2.7 CURRENT SYSTEMS AND THEIR INTERACTION METHODS

Below is Table 2.1 which summarizes the tools which are currently available and the methods they use for allowing input and providing output.

INPUT	**OUTPUT**			
	Refreshable pin	**Audio**	**Touchpad with Overlays**	**Forced Feedback**
Keyboard	Minagawa et al	IGraph Lite TeDub IC2D Kevin Plumb Yu et Al IVEO Metatla et Al	Kevin IVEO	
Voice		TDraw		
Refreshable pin	Wall & Brewster			
Touchpad	Tac-tiles IVEO	Audiograph Plumb Tac-tiles Kevin Tactis AudioGraf	Kevin Tac-tiles Tactis	
Forced Feedback		McGookin & Brewster Yu et al		Yu et al McGookin & Brewster
Joystick/mouse		TeDub IVEO	IVEO	
Webcam		Digitizer Audio Graph		

Table 2.1 - Diagramming tools for the visually impaired and the tools input and output methods.

When looking at the above solutions one can identify a few basic problems:

1. Output via audio/text is linear (slow) in comparison to visuals.
2. Feedback devices are hard to use and can be exhausting.

3. Many touchpads (ie: IVEO) must be calibrated in order to overlay the touchpad with a tactile diagram and calibration can be difficult to perform.
4. The overlays used with the IVEO often involve fine detail which is difficult to feel with one's hand.

It is the intention of this author to investigate a solution that uses a touchpad, voice and touch input and audio output. This decision was made based on investigation of the above Table 2.1. There appears to be a gap in the amount of solutions which make use of voice recognition and although this gap exists for using forced feedback, the technology needs to be developed further in order to avoid existing problems. While most solutions provide audio as the main source of output, this is a mode of output which is unavoidable with current technology. The goal however is to make the audio less linear by allowing the user more control over the output.

In order to use the input and output methods as stated above to create a tool, a list of guidance items were compiled.

2.8 GUIDANCE ON DIAGRAMS FOR THE BLIND

This research has accumulated a variety of guidelines that can help make working with diagrams accessible to the blind.

2.8.1 General Guidance

1. Use non-pixel mapped graphics (Donker et al, 2002).
2. Avoid using similar sounding words in descriptions (Donker et al, 2002).
3. Allow the user to easily toggle the tasks of creating and reading diagrams.
4. Tools to support the blind should use a minimum of keyboard input and auditory output. Where tactile devices are available they may be used as alternate input and/or output devices. Voice recognition can also be used as an alternate mode of input.

2.8.2 Guidance on Aural Descriptions of Diagrams

General guidance on providing aural description of diagrams includes:

5. Keep descriptions short and precise (Donker et al, 2002).
6. Use contextual reinforcement for relationships (Donker et al, 2002).
7. State why the diagram is there (Horstmann et al, 2004).
8. Include all features of the diagram (Horstmann et al, 2004).
9. Minimize interpretation (Horstmann et al, 2004).
10. Improve user performance by substituting non-verbal descriptions with verbal descriptions (Metatla et Al, 2007).

2.8.3 Guidance on dealing with complexity

11. Provide an overview and then offer further details (Horstmann et al 2004, Strain McAllister, Murphy, Kuber and Yu, 2007).
12. Differentiate between different levels in diagrams (Horstmann et al ,2004; Edman, 1992).
13. Use chunking to reduce the amount of to-be-treated elements (Cornoldi, 2000).
14. Divide information that requires processing into subparts (Cornoldi, 2000).
15. Present line diagrams as a "layered" sequence of diagrams (Francioni and Smith, 2002; see also Aldrich and Sheppard, 2001; Edman, 1992; Metatla et al, 2007).
16. Use strategies for working with spatial manipulation to overcome task difficulties (Cornoldi, 2000).

2.8.4 Guidance on Creating Diagrams

17. The system should automate as much of the creation process as possible and guide the user through as much as possible of the remainder of the process.
18. Make use of 3x3 grids to control the location of objects to increase accuracy for visually impaired when locating objects (Kamel and Landay, 2000; see also Strain et al, 2007). The use of recursive grids can achieve more detail; however, a 27x27 grid should be the maximum size used.
19. Offer users preference options before rendering the drawing. These preferences should include items such as location of objects, the level of the drawing (detail offered) and objects to appear in the drawing.

2.8.5 Guidance on working with elements of diagrams

20. Identify components, clarify labeling and identify differences. (Horstmann et al, 2004)

21. Where appropriate, describe visual aspects of the diagram. Use terms such as ‘egg shaped’, vertical, and perpendicular. (Horstmann et al, 2004)

22. Order descriptions; provide start points and direction. (Horstmann et al, 2004; see also Paladugu et al, 2010)

23. Allow users to locate and relocate important points and offer “[s]ome guideline or frame of reference [because it] is needed” (Kamel and Landay 2000; see alsoChoi and Walker, 2010).

2.8.6 Guidance on working with tactiles

24. Prevent tactile illusions by keeping the size of the stimulus as small as possible (ie. Around the size of one’s hand) (Heller, 2003; see also Edman, 1992).

25. Allow two handed investigation (Wall and Brewster, NordiCHI 2006; see also Edman, 1992).

26. Provide reference points and memory aids (Wall and Brewster, NordiCHI 2006) to allow for easy navigation.

27. Preserve visual aspects to provide for collaboration with sighted individuals (Wall and Brewster, NordiCHI 2006). Colour can even be used to aid the visually impaired who have some sight (Jansson, 2000).

28. To allow for the largest audience, ensure that Braille is used as only a supplemental output source.

29. Use easily identifiable symbols such as squares, triangles and circles (Edman, 1992; see also Canadian Braille Authority English Braille Standards Committee, 2003; Paladugu et al, 2010)

30. Make use of textures, height and dead space to help readers translate diagrams (Canadian Braille Authority English Braille Standards Committee, 2003; see also Sheppard and Aldrich, 2000)

2.9 CONCLUSION

Although diagrams provide many benefits to the sighted, they provide boundaries for the visually impaired. Most current research attempts to overcome these boundaries by providing products that can help the visually impaired read and/or create these diagrams. These tools are concerned with translation of diagrams and ignore providing the visually impaired with similar advantages as sighted. As well, these tools are usually specific to one type of diagram. This requires a user to navigate between a number of different programs in order to create different diagrams. This can increase the user's mental load, which should actually be alleviated by the use of diagrams. In order to overcome these problems a program is needed that can allow the user the flexibility to create an assortment of diagrams automatically. At the same time it will allow the user to read and edit these diagrams such that they can collaborate with sighted users.

CHAPTER 3

3 REQUIREMENTS

As mentioned in Chapter 2, there exists the need to provide visually impaired persons with the ability to access diagrams, especially for the purposes of learning in schools and collaboration in the work world. Instead of only providing the user with a verbal description of the diagram we should focus on actually providing them some of the same benefits sighted individuals experience. In dealing with a special needs group we must take into account the modalities we have available to us for input and output. If we take the above mentioned items, we can begin to accumulate a list of requirements.

3.1 DIAGRAMS FOR SCHOOL AND WORK

Diagrams are often used at school and at work. In these circumstances it is often to collaborate with others, learn about something quickly or even use as a reference. In order to have a successful system for these environments the system needs to:

1. Support a variety of diagrams (ER Diagrams, family trees, etc).
2. Support the export and import diagrams between different programs.
3. Allow collaboration with sighed users.
    a. Create a visual representation of the resulting diagram
    b. Ensure the system can be easily utilized by sighted users
4. Be affordable because many of these users will be students. Many of these people already have or are purchasing expensive assistive equipment. As well, visually impaired persons also list cost as a barrier when it comes to them working with new technologies.

It would also be nice if this device could be utilized for alternate uses other than just for accessing diagrams.

5. Be portable so that these devices can be carried to classes or meetings.

3.2 PROVIDING THE BENEFITS OF DIAGRAMS

The following is a description of the benefits diagrams provide and how these translate into requirements in the proposed system.

1. Diagrams highlight key concepts and relationships which allow for critical thinking. Highlighting key concepts helps users quickly understand the structure of relationship based diagrams. For the diagrams that will be supported, the key concepts will be the objects, their attributes, and their relationships. (Refer to section 4.1)
2. Diagrams depict "connections and contradictions between existing knowledge (schemas) and new information" (Bromley et al, 1999);
3. Diagrams assist one's memory by focusing on the most important information, and encourage one's understanding of the material depicted in the diagram.
    a. Creation of diagrams requires one to be actively involved in understanding the diagram. To allow the user to focus on understanding the material versus physically using the system to create the diagram, users must be able to easily:
        i. define the type of relationship based diagram to be created,
        ii. create the components of a relationship based diagram, and
        iii. modify the components of a relationship based diagram.
    b. This can also be done by chunking information. The diagram should be chunked into parts that build upon each other. Chunking can consist of answering the following questions:
        i. What objects exist?
        ii. What objects are related?
        iii. What are the objects attributes?
        iv. Where is the object located in the diagram?

    c. Allowing users to define how much information and detail is returned helps them to only sort through the information they need. This can assist in the user's selecting a method for gaining understanding.
    d. Allowing users to return to information quickly will help reduce mental load. This can be done by allowing users to book mark specific objects which provides an easily accessible reference point.

3.3 OUTPUT MODALITIES

When working with the visually impaired we have touch and sound available as a method of output. For this reason, the following requirements must be met to provide proper output for the intended user.

Chapter two, section seven suggests the following are good choices for further investigation of output methods; so one or more of the following should act as the output source(s):

1. Audio using voice and/or sounds.
    a. Make verbal information accessible in a less linearly fashion than traditional methods which usually involve reading the entire description of the diagram. This will make the system more efficient to use then systems where one must listen to the entire listing.
    b. Use sounds that match the tasks and to help reduce the time of aural descriptions.
2. Use an overlay to cover a touchpad. An overlay provides output by defining spaces on a touchpad for the user. This prevents the user from becoming disoriented on the touchpad.

3.4 INPUT MODALITIES

For inputs we have available similar techniques to those available to sighted persons. In Chapter 2.7, it is suggested that the following be concentrated on because of the room for improvements in this area:

1. Touchpad

    a. Do not use a stylus as they are difficult to utilize (Cohen et al, 2006; see also Wall and Brewster, NordiCHI 2006).
    b. Do use an overlay. Ensure that shapes are easy to distinguish.

2. Voice
    a. Commands should be words and not short forms of words. Similarly, do not use numbers that refer to a specific command because this adds to the user's mental load.
    b. Commands should be consistent.
    c. Limit vocabulary variations.

3.5 USABILITY

To ensure usability of the system, the entire system should meet the guidance items identified in Chapter 2.8. The commands and gestures must be easy to remember and to perform. The basic functions for this system will be reading, creating and modifying diagrams. These tasks can be complicated so the system needs to present them to the user in an easy to understand format. Users must also be able to navigate around diagrams without getting lost.

CHAPTER 4

4 OVERLAY DESIGN AND EVALUATION

The design of a system to be used by the visually impaired to read diagrams requires two steps. The first step involves the design and evaluation of an overlay for the iPad. This step will be discussed in this chapter. The second step involves building on the information gathered from evaluating the overlay and will be discussed in Chapters 5 and 6.

Design of the overlay needed to meet guidance items 24-30 and so the following prototype was created. The prototype is made out of a piece of cardboard with elastic to hold it onto the ipad and prevent it from shifting (Refer to Figure 4.1). The cardboard cutouts make use of height to distinguish between grid items and buttons (Guidance 30). Nine squares were cut out to form a 3x3 grid. Four buttons were cut out left side of the grid.

The buttons are:

1. circle representing the Mode button,
2. square representing the talk button, and
3. a triangle pointing up and a triangle pointing down representing the scrolling buttons.

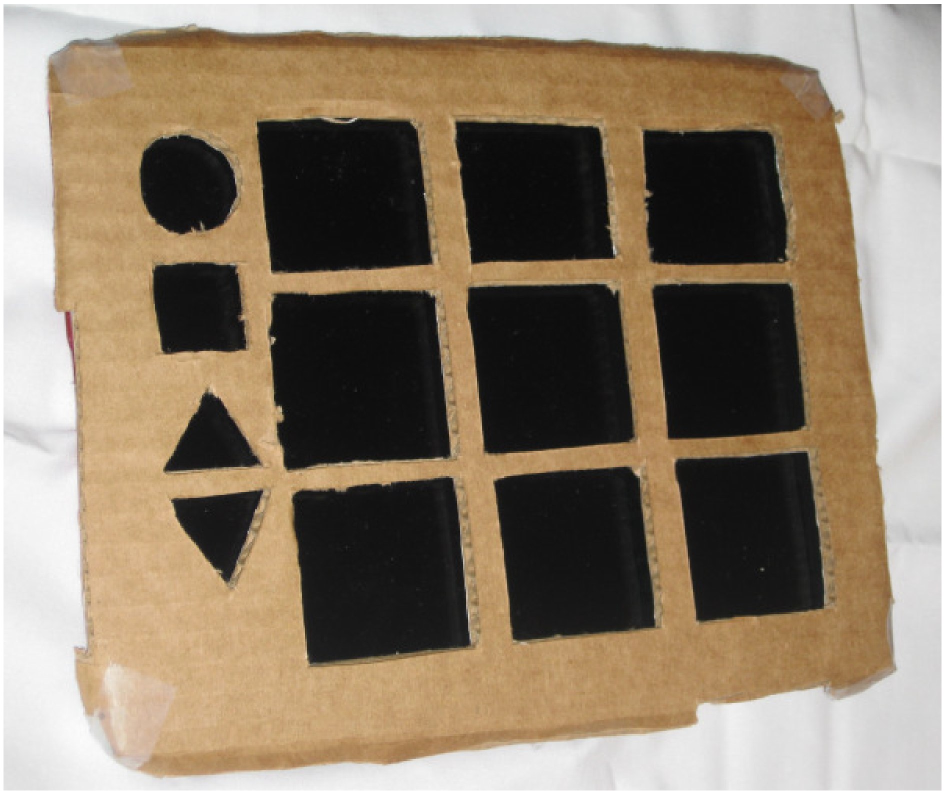


Figure 4.1 - VATagrams Overlay placed on the iPad

Buttons were placed to the left side of the screen because most people are right hand dominant and will want to perform the difficult gestures and navigation with their dominant hand. The button order was selected from top to bottom in order of importance and expected amount of use.

Cut outs were chosen over raised buttons as per the recommendation made by Bussell (2003) and they would still allow sighted users the ability to see through to a visual display of a diagram (Guidance 27). The simple shapes were chosen for the grid and buttons because they are easy to identify (Guidance 29). See Figure 4.2 below for an example of how the graphics could be displayed through the overlay.

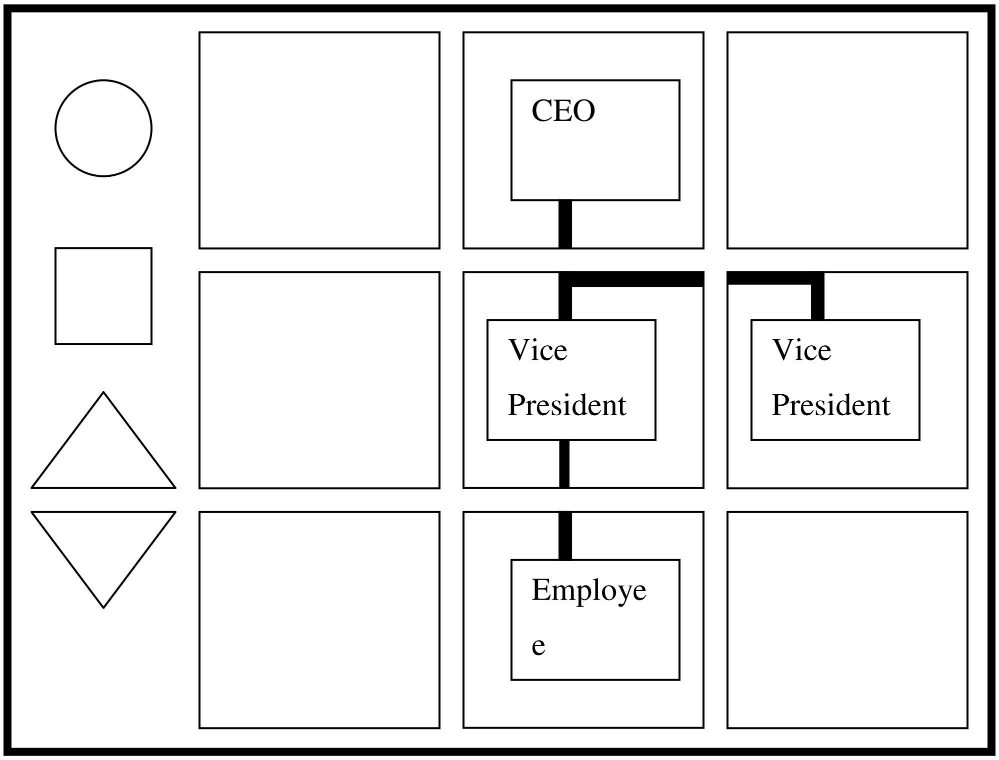


Figure 4.2 - Example of the visual organizational diagram being displayed by VATagrams at the highest zoom level (1:1).

For this project, lack of screen space naturally made room limited and so a Braille keyboard was dropped (Guidance 28) in favour of input methods that are accessible by a wider range of users. The natural size of the iPad makes two handed investigation possible (Guidance 25), yet is still small enough to avoid any tactile illusions (Guidance 24). The division of the overlay, grid display area versus button area, makes natural reference points; whereas the layout of the buttons ie: the scroll buttons are above one another, helps remember locations (Guidance 26).

Finally, in order for the overlay design to be feasible, users must be able to perform a number of different gestures in the confined spaces of the overlay with different sized hands and fingers. Gestures must be easy to perform in the spaces.

4.1 PROTOTYPE DESIGN FOR OVERLAY EVALUATION

A basic prototype was developed so that the system would read out the name of the recognized gesture when a gesture was performed. The system can recognize the following gestures:

1. long Press
2. single tap
3. double tap
4. pinch in
5. pinch out
6. single finger horizontal swipe
7. two finger horizontal swipe
8. three finger horizontal swipe

4.2 OVERLAY EVALUATION DESIGN

The evaluation is designed to compile the following results.

1. How many attempts the user must make in order to have the correct gesture will provide insight into accuracy.
2. The time needed to complete a gesture or a set of gestures will show how easy a gesture is to perform (ie: the faster you can perform the gesture the easier it is to perform).
3. The participant's perceptions regarding the ease of performing the gestures.
4. Other observations and comments from participants may provide insight into problem areas.

Participants were given a quick tutorial on the gestures, buttons and grids as listed above. Participants were asked to perform the following tasks:

1. Touch the mode, speech and scrolling buttons and invoke recognition by the system.

2. Use the pinch in gesture within a grid location and invoke recognition by the system.
3. Use the pinch out gesture within a grid location and invoke recognition by the system.
4. Use the horizontal swipe gesture (with one, two and three fingers at a time) within a grid location and invoke recognition by the system.
5. Use the tap gesture (with one, two and three taps at a time) within a grid location and invoke recognition by the system.
6. Use grid location gestures (pinch in, pinch out, horizontal swipe and tap) in conjunction with the buttons. Here the user would press one button while performing a gesture in a grid location directly following the press.

The following information was recorded by the researcher on a worksheet as the participant completed each task:

1. Time to complete the task, (the researcher used a stopwatch to track time in seconds)
2. Participant's success rate in completing the task and/or how many attempts to complete the task.
3. Any observations of interest.

At the end of the session, participants answered a questionnaire regarding their opinion on the ease of performing the gestures using the overlay. (Refer to Appendix C)

4.3 OVERLAY EVALUATION RESULTS

All of the participants selected for this evaluation were sighted; however, two were blindfolded while they performed the experiment. Blindfolded participants were used because of the difficulty in finding visually impaired subjects (Califf, Goodwin and Brownell, 2008; and see also Schneider and Strothotte, 2000). It should also be mentioned that the results obtained from the simulated visually impaired subjects should be similar to someone who recently became visually impaired (McGookin et al, 2008).

Of the participants tested, 3 were male and 1 was female. Both of the blindfolded participants were male. One of the sighted participants was female and one was male. Only blindfolded participant 1 had no prior experience with an iPad, iPod or iPhone.

4.3.1 Attempts per Task

Tables 4.1a, 4.1b and 4.2 below show the number of attempts per participant to complete each task. In general, there were less attempts by the sighted than the blindfolded participants.

	Long Press mode	**Long Press talk**	**Long Press scroll up**	**Long Press scroll down**	**single tap grid**	**double tap grid**
Person 1 Blindfolded	4	10	1	2	1	2
Person 2 Blindfolded	1	1	1	1	1	1
Person 1 Sighted	1	1	1	1	1	1
Person 2 Sighted	2	1	1	1	1	1

Table 4.1a - Attempts per task per participant

	triple tap grid 1	**1finger swipe Grid 9**	**2finger swipe Grid 3**	**3finger swipe Grid 5**	**pinch in grid 7**
Person 1 Blindfolded	1	1	1	3	1
Person 2 Blindfolded	4	2	1	6	2
Person 1 Sighted	1	1	4	1	1
Person 2 Sighted	1	1	1	3	1

Table 4.1b - Attempts per task per participant

	Person 1 Blindfolded	**Person 2 Blindfolded**	**Person 1 sighted**	**Person 2 sighted**
Pinch out grid 8	3	1	1	1
Press mode/pinch in grid 4	2	4	1	1
Press talk and 3 finger swipe grid 2	1	2	2	2
Press scroll up and double tap grid 8	1	1	1	1
Press scroll and pinch out grid 1	1	1	1	5
Press mode and 1 finger swipe grid 3	1	1	1	1
Press scroll and 2 finger swipe grid 4	2	1	1	1
Press scroll up and single gap grid 5	1	1	1	1
Press talk and double tap grid 3	1	1	1	1

Table 4.2 – Attempts per task per participant

Figure 4.3 below illustrates the average amount of attempts by participant group to perform a specific gesture or task.

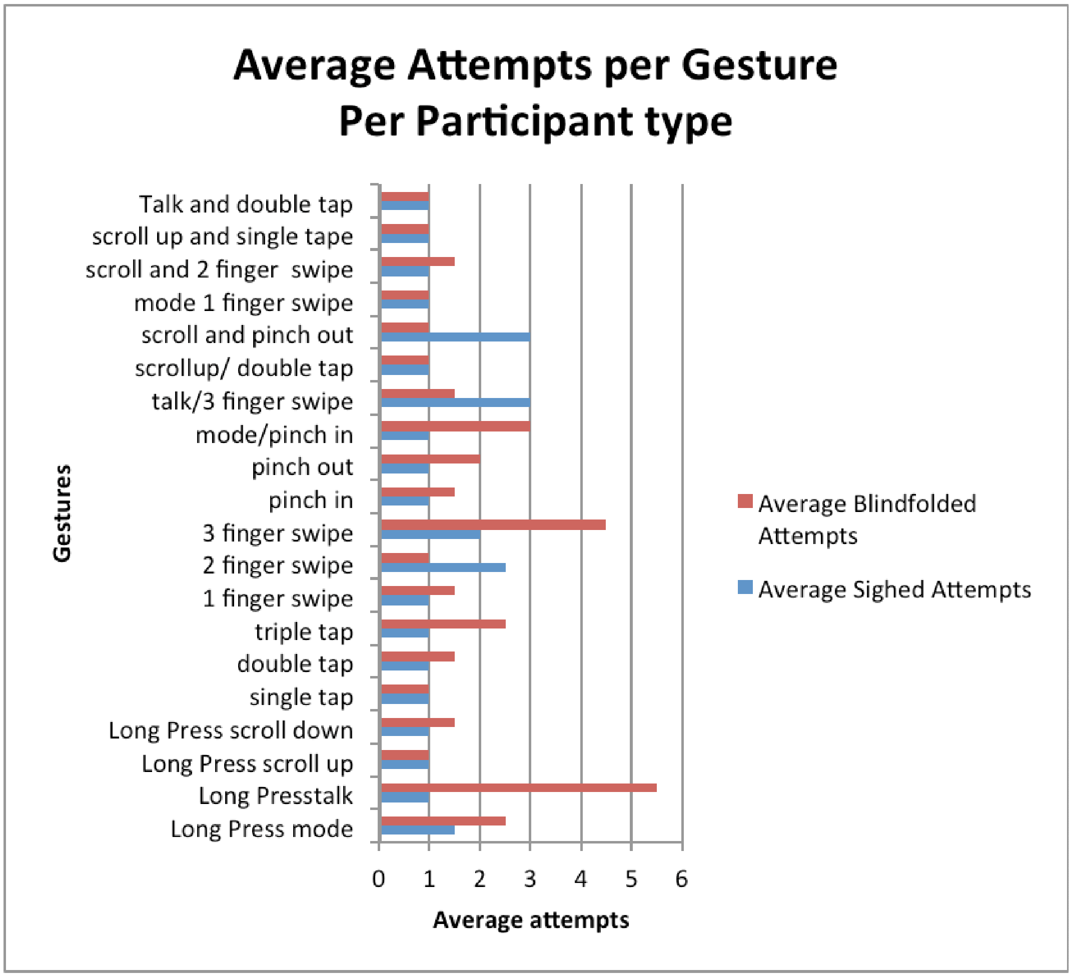


Figure 4.3 – Average attempts per Gesture per Participant type.

4.3.2 Time per Task

The longest single gesture to perform by the blindfolded was the long press on the talk button. It took 32.5 seconds. The longest single gesture to perform by the sighted was the two finger swipe at 20 seconds.

The longest gesture set to perform by the blindfolded was pressing the mode button and then performing a pinch in grid 4; it took 45 seconds. The longest gesture set to perform by the sighted was pressing the talk button and then performing a 3 finger swipe in grid 2; it took 13.5 seconds. Refer to Figure 4.4 below for the average time it took for each participant type to perform the gestures and gesture sets.

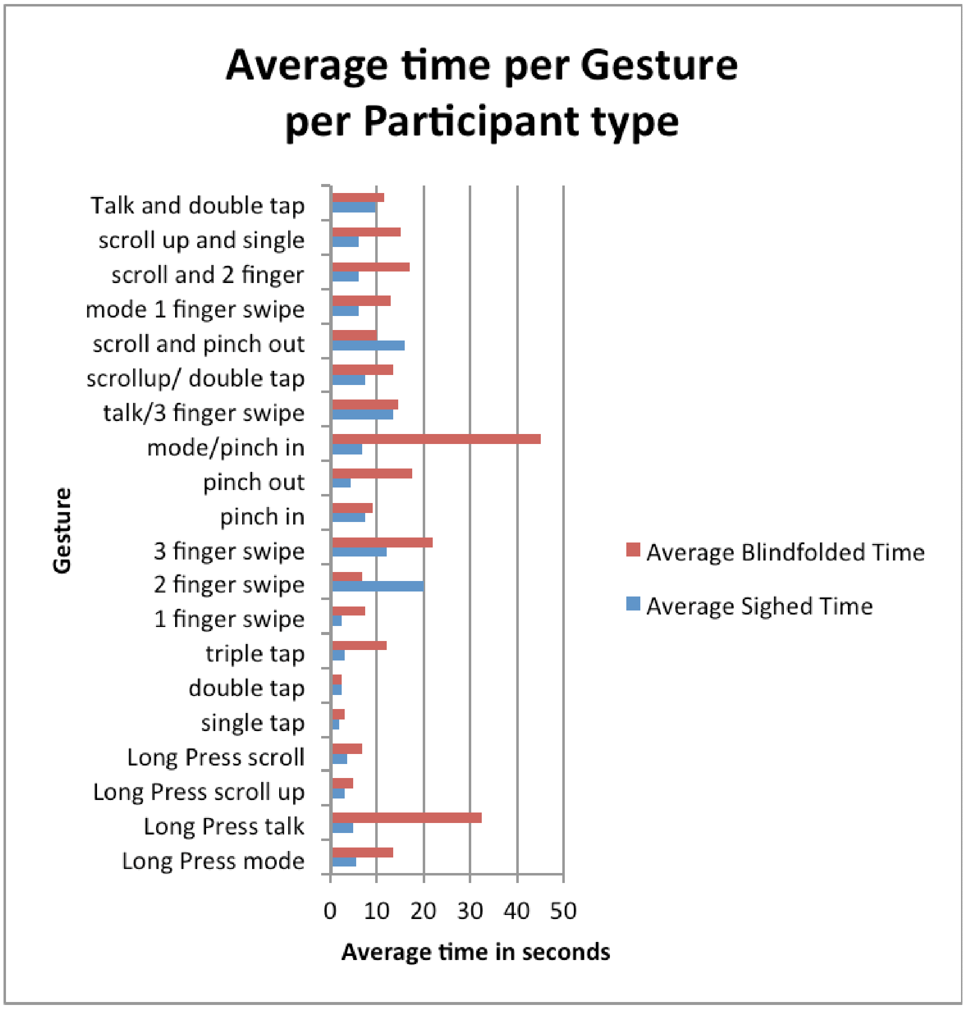


Figure 4.4 - Average time per Gesture per participant type

4.3.3 Participant perception on ease of use

The questionnaire asked participants to rate each gesture on a scale of 1-5 where 1 was extremely difficult and 5 was extremely easy. The following is a list of the number of participants (per participant type) who rated each question as a specific value. See Table 4.3 below for a listing of the questions and the scores by participant group.

Participant type	**Very Difficult (1)**	**Somewhat Difficult (2)**	**Neither Difficult nor Easy (3)**	**Somewhat Easy (4)**	**Extremely Easy (5)**
How easy was it to press the mode button?					
Blindfolded				2	
Sighted					2

How easy was it to press the talk button					
Blindfolded				2	
Sighted					2
How easy was it to press the scroll buttons					
Blindfolded			1	1	
Sighted					2
How easy was it to pinch in on a grid?					
Blindfolded			2		
Sighted				2	
How easy was it to pinch out on a grid?					
Blindfolded		1			1
Sighted		1		1	
How easy was it to horizontally swipe a grid with one finger					
Blindfolded				1	1
Sighted				1	1
How easy was it to horizontally swipe a grid with two fingers?					
Blindfolded		1			1
Sighted		1		1	
How easy was it to horizontally swipe a grid with three fingers?					
Blindfolded	1			1	
Sighted	1		1		
How easy was it to single tap a grid?					
Blindfolded					2
Sighted					2
How easy was it to double tap a grid?					
Blindfolded				1	1
Sighted					2
How easy was it to triple tap a grid?					
Blindfolded			1		1
Sighted					2
How easy was it to use different gesture in combination with buttons?					
Blindfolded		1		1	
Sighted				1	1
Overall, how easy was it to use the techniques?					
Blindfolded			1	1	
Sighted				1	1

Table 4.3 – Listing of the ratings provided by participant types.

The average scores by each user group for each task are displayed in Figure 4.5 below.

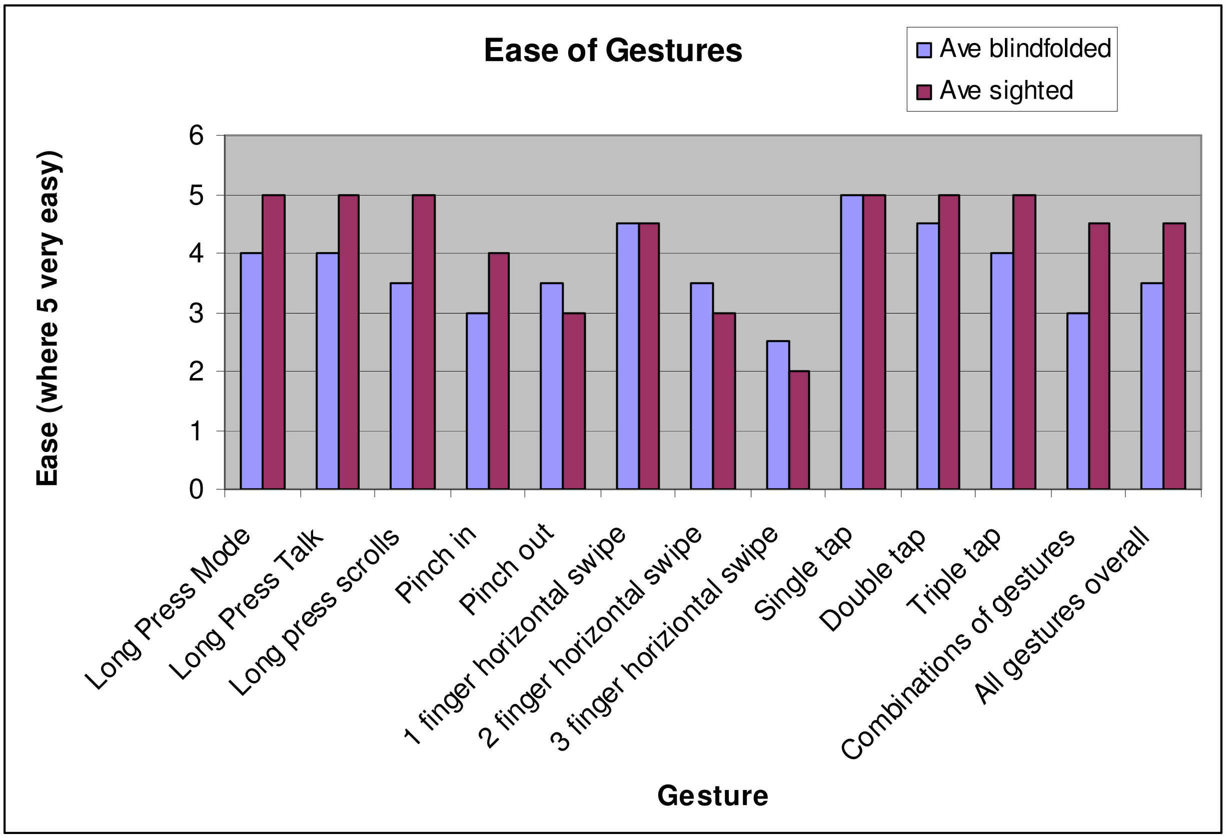


Figure 4.5 - Ease of performing each type of gesture rated by participants

4.3.4 Observations of Interest

There were two instances of performing gestures in the wrong grid area. One blindfolded participant performed both instances.

Two participants commented on the difficulty of the three finger swipe because of their finger size. One blindfolded participant commented on the difficulty of the triple tap.

The two blindfolded participants mentioned that the touch screen was too sensitive to their movements. One of these blindfolded participants also commented that a more rigid overlay would be helpful as they felt the overlay moved too much under their touch.

4.4 DISCUSSION

Although the long press on the talk button had the longest average time for the blind folded (see Table 4.4 below), the number of attempts by the participants could be a factor. It should be noted that the same participant who had the most attempts was the participant who did not have any previous experience using an iPad, iPod or iPhone. The participant held the long press for such a long period of time that the system recognized it as a canceled request (a common feature of Apple touch products).

	Long Press mode	Long Press talk	Long Press scroll up	Long Press scroll down
Blindfolded Participant 1 Time in Seconds	22	60	5	10
Blindfolded Participant 2 Time in seconds	5	5	5	4
Blindfolded Participant 1 Attempts	4	10	1	2
Blindfolded Participant 2 Attempts	1	1	1	1

Table 4.4 - Time in seconds and attempts to perform the Long Press per blindfolded participant

The participants rated the single tap and double tap as the easiest gestures to perform. Both gestures had averages of 5 or extremely easy. This coincides with the results where the single tap was recognized by the system in all cases and the double tap was repeated once by one participant.

The following findings were used to design the command set.

1. Although three participants rated performing the commands in combination as a 4 or higher, these commands required extra time to perform. The initial time may be minimal at 13 seconds for a combination of commands and 9 seconds for one command but if the system misreads a command or the participant uses one incorrect gesture in the set,

repetition of the command at least doubles the time. For these reasons commands will be limited to one gesture.

2. The three finger horizontal swipe rated the lowest with an average rating of 2.5 or somewhat difficult. It was also the only gesture where all four participants needed to repeat the gesture multiple times before the system recognized the gesture correctly. A few of the participants mentioned that the size of their fingers in comparison to the size of the grid area made performing this gesture difficult. This gesture will not be used.

3. Two participants rated the pinch out as somewhat difficult but the pinch in did not rate as low. These commands are performed similarly and have similar average rates of attempts (Pinch out at 1.5 attempts and pinch in at 1.25 attempts) so more data needs to be collected to determine the actual reason participants rated this gesture low.

4. The following gestures, based on their ease of use and the number of attempts to perform the command will be the primary gestures: single tap, double tap, and long press.

5. To provide the extra rigidity as requested by one of the participants ,the overlay will be taped to the surface of the iPad. This is not an optimal solution; however, it is sufficient for prototyping.

CHAPTER 5

5 PROTOTYPE DESIGN

In order to address the requirements determined in Chapter 3, a series of prototypes were created. These prototypes were designed to determine if a visually impaired person could use the command set, iPad and overlay for reading, editing and creating diagrams. The following sections explain the design methods used for all the prototypes:

1. Types of diagrams supported
2. Storage of diagrams
3. Drawing a visual representation of the diagram
4. Diagram Creation
5. Diagram Exploration
6. Technical Tools

The final section discusses the specifics for each prototype.

5.1 TYPES OF DIAGRAMS SUPPORTED

For the purposes of this thesis, the prototypes will focus on creating and translating diagrams which depict relations. For this reason the following diagrams are looked at: UML based ER-Diagram, Traditional ER-Diagram, Organizational, and Family Trees. At the lowest level each is composed of relationships and objects. Each of these may have one or more attributes.

The following table (Table 5.1) breaks down the visual aspects of a diagram into its individual parts.

Diagram Type	**Layout Type**	**Objects**		**Relationships**	
		Object Name	**Attributes**	**Relationship Type**	**Attributes**
UML Based ER-Diagram	No forced layout	Tables	Expandable rectangles with text inside. This rectangle is conjoined with the Attributes table	Between two tables	Line between the tables with text above the line at 3 locations: beside each table(square) and between the tables
		Attributes	Expandable rectangles with text inside. The rectangle is conjoined with the Table's rectangle. This rectangle is shared with all the attributes		
		Primary Key	An attribute that has "PK" written before the text		
Traditional ER-Diagram	No forced Layout	Tables	Squares with Text	Relationships between two tables	Diamond connected by a line to each table. There is text in the diamond
		Attributes	Ovals with text	Relationship between a table and a field	Line between the table and the field
		Primary Key	Oval with underlined text		
Organizational Chart	Top Down Layout	Person	Rectangle with name, title	Relationship between two persons	Line between two persons

Diagram Type	**Layout Type**	**Objects**		**Relationships**	
		Object Name	**Attributes**	**Relationship Type**	**Attributes**
Family Tree	Bottom Up Layout	Male	Square with name, date of birth	Married	Horizontal line between two persons side by side. Date of marriage
		Female	Circle with name and date of birth	Married or Common Law	Horizontal line between two persons side by side
				Child of	Vertical line between at least two persons

Table 5.1 - Breakdown of diagrams into their components.

The information provided by table 5.1 above was used to determine the database structure. Refer to Appendix A for the database structure.

In order to support the above mentioned diagrams the shapes displayed in Figure 5.1 are required.

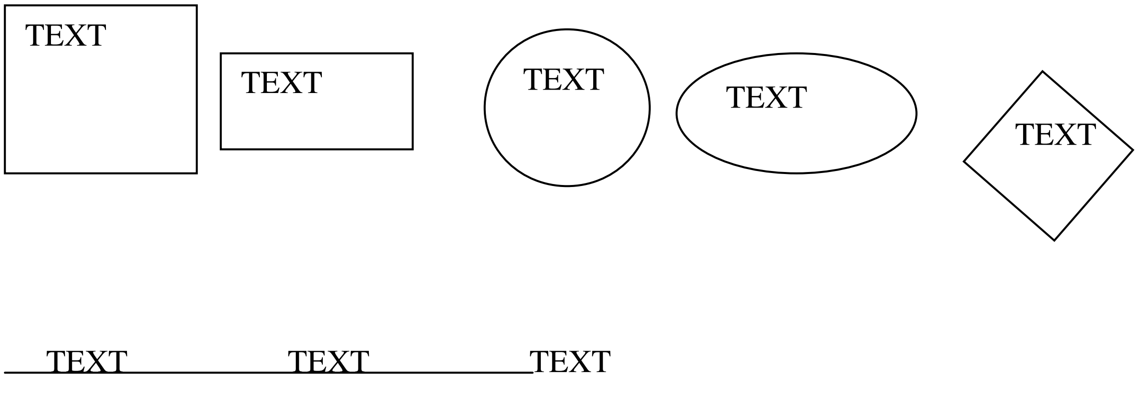


Figure 5.1 - Shapes defined in the system. From r-l and t-b: Square, rectangle, circle, oval, diamond and relationship line

Square – A square drawn with the option to include text inside the square.

Rectangle – A rectangle drawn with the option to include text inside the rectangle.

Circle – A circle drawn with the option to include text inside the circle.

Oval – An oval drawn with the option to included text inside the oval.

Diamond – A diamond drawn with the option to include text inside the diamond.

Line – A line drawn between two objects. There is the option to include text above the line at leftmost, centre and rightmost locations. Line thickness will vary in order to be displayed properly behind the overlay (See section 4.5).

Objects may be made up of one or more shapes and exist in one grid location (defined in Section 5.5). For example in Figure 5.2, in the instance of a table object in an ER-Diagram, this could include conjoining two rectangles with the same widths but different heights (one rectangle for the table and one for all the attributes).

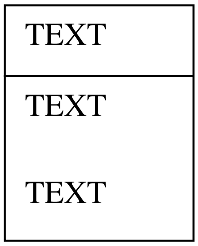


Figure 5.2 - Example of conjoined rectangles

A complete tool should support three types of layout.

1. Vertical hierarchical diagrams
    a. Top Down Layout refers to a hierarchical diagram where the parent object(s) occurs at the top of the diagram. Logic indicating child and parent nodes is involved. For example, in an organizational diagram, the boss would appear above his or her employees.
    b. Bottom Up Layout refers to a hierarchical diagram where the parent object(s) occurs at the bottom of the diagram. Logic indicating child and parent nodes is involved. In a family tree diagram, the grandparents may appear at the bottom of the diagram with their children and grandchildren above them.
2. Horizontal hierarchical diagrams

    a. Right Aligned Layout refers to a hierarchical diagram where the parent object(s) occurs at the right most side of the diagram. Logic indicating child and parent nodes is involved. For example, in an organizational diagram, the boss would appear to the right of his or her employees.
    b. Left Aligned Layout refers to a hierarchical diagram where the parent object(s) occurs at the left most side of the diagram. Logic indicating child and parent nodes is involved. For example, in an organizational diagram, the boss would appear to the left of his or her employees.
3. User Specified Layout occurs in diagrams where no hierarchical organization exists and the organizational structure of the diagram is not always important. In these diagrams, users can completely control where the objects appear. There are no child and parent nodes and so for diagrams like ER-diagrams, object positioning does not have great significance.

The breakdown of these diagrams shows that basic relationship diagrams conform to the structure of objects, attributes and relationships. Keeping these principles in mind, in order to provide proof of concept, two diagrams will be used; UML ER-Diagram and Organizational Diagram. These diagrams have been chosen because they represent the widest array of fundamental structural differences. There are substantial differences in the User Specified layout vs. the hierarchical layouts, but since the differences between hierarchical layouts is nominal, only one layout needs to be tested. Similarly, the difference in implementing the different shapes is nominal with the exception of in UML based ER-Diagrams where it is actually two shapes together. For this reason, only the rectangle and lines with text will be implemented as required by the aforementioned diagrams.

5.2 STORAGE OF DIAGRAMS

Each diagram is broken down into data information that is stored in a database. This information includes items such as the objects and their locations in the diagram. It was decided that information would be stored in a database as this format allows information to be easily and efficiently accessed by the system. This data also has the ability to be shared (Section 6.2.1).

The diagram definitions as mentioned in section 4.1 are stored in the database (Refer to Appendix B). These definitions act as the templates for each different type of diagram. Keeping the templates stored in the database will allow functionality for importing diagram templates to be added at a later time; currently one must manually enter the template data into the database before the app is installed on the iPad.

The templates contain information needed to tell the system what object types, attribute types and relationship types are available. For example: In an organizational diagram, the object types are usually defined as a person or an employee; however, the template could be setup to be more specific and define a woman or a man as the object types. This template is used to draw the information needed to form the language used by the system to verbalize information to the user.

All information entered by the user when creating the diagram is saved to the database but to allow for quick read access, the information is also stored as objects and variables within the code. This reduces the time spent querying the database each time the diagram needs to be read and navigated. If a user creates a new diagram, the user is asked for the diagram type. The prototypes load from the database the appropriate template information. If the user loads an existing diagram, the prototype loads the appropriate template and diagram data.

Figure 5.3 shows the flow of data between storage and the modalities.

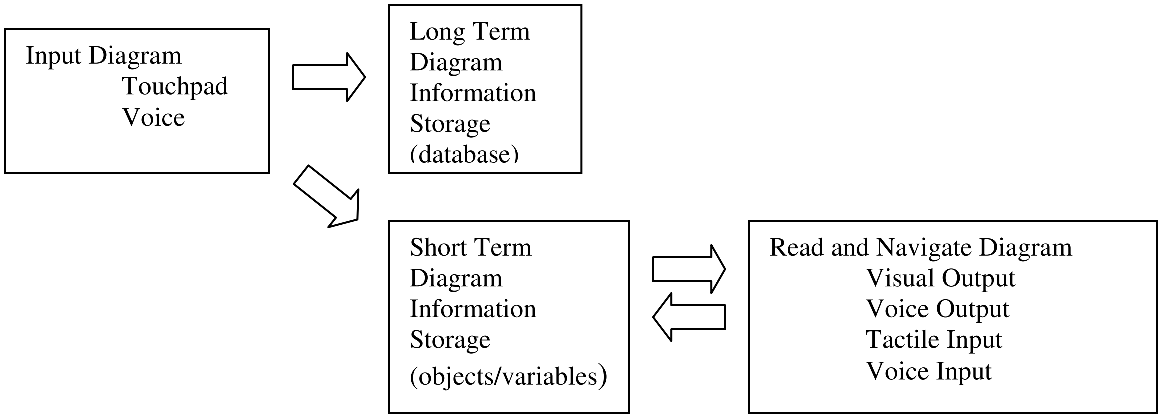


Figure 5.3 - System’s input and output modality flow

5.3 DRAWING A REPRESENTATION OF THE DIAGRAM

Based on Kamel and Landay's (2000) research, anything larger than a 27 x 27 matrix is too difficult to conceptualize. For this reason the system supports diagrams of up to 729 objects. However, in some diagram types, it is most likely that fewer objects are supported because of their layout. For example, in a Family Tree, there are usually only two topmost objects. While there is the ability for up to 27 levels in the tree, the most objects that can be had at any levelare only 27.

5.4 DIAGRAM CREATION

Using a combination of voice and gestural commands, users are able to create diagrams (Refer to Appendix B for a list of commands). Users can choose to make an object and assign attributes and relationships to the object. The system lets the user know that an item has been created by stating the information that has been entered into the system.

5.5 DIAGRAM EXPLORATION

Once again the user can use voice and gestures to command the system (Refer to Section 5.7.1 for a list of commands). The system provides appropriate output via speech. Users can control what output they receive at different levels:

1. overview of the entire diagram,
2. reading one or more objects,
3. reading attributes of one or more objects, and
4. reading relationships of one or more objects.

Users also have the ability to search for objects and attributes and even jump to the location of a particular object.

The system uses a similar technique to represent locations of objects to users as what Kamel and Landay (2000) used. The system places one object in each grid location. The grid is a 3x3 recursive grid. Each level is represented by a number equal to that of its location on the grid in comparison to a number keypad (see Figure 5.4). Each grid location has two more recursive levels; these are referred to as zoom levels. So at the lowest zoom level, you would have a grid location comprised of one number and at the highest zoom level, you would have a grid location represented by three numbers (See Figure 5.5).

1	2	3
4	5	6
7	8	9

Figure 5.4 - Grid number layout 1

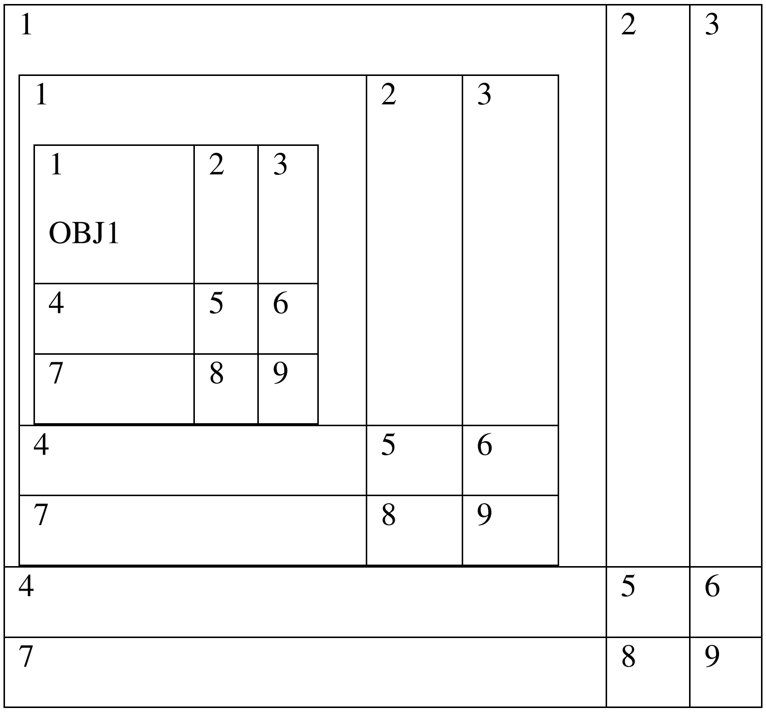


Figure 5.5 - Example: the location of OBJ 1

5.6 TECHNICAL TOOLS

There are a number of different tools which were utilized in the development and design of the prototypes. They are:

1. Hardware,
2. Development Environment
3. Gesture Recognizers
4. Graphics
5. Sound
6. Speech recognition software and text-to-speech engine, and
7. Database platform

5.6.1 Hardware

With the introduction of Apple's iPad technology (a 9.5" x 7.5" x 0.5" touchpad pc with integrated GPS, WI-FI and 3G), the possibility of integrating voice and touch into a solution has become much simpler.

5.6.2 Development Environment

Apple provides a Software Development Kit (SDK) for Apple's line of touch products (iPad, iPhone, iPod). This SDK includes Application Programming Interfaces (API) and utilizes the language objective-C.

5.6.3 Gesture Recognizers

For handling the gestures used by the prototypes, the gestureRecognizer class was used. This is a class provided in the API and while it does speed up development time, some of the methods are weak in that they do not have enough functionality and the work around causes the system to be overly sensitive to certain motions. For example, when recognizing pinches, the gesture recognizer does not automatically distinguish between a pinch in and a pinch out. This gestureRecognizer can return the velocity of the pinch so in order to distinguish whether it is a pinch out or a pinch in, one can use the velocity. A positive value would signify a pinch out and a negative value a pinch in. The system acts overly sensitively because if a user performs the pinch gesture and slightly alters the direction of their fingers at the end, it can result in the system recognizing the wrong pinch.

While this is not the most optimum behavior by the system, it was decided to continue using the built in gestureRecognizers because development time for creating new ones would not have met the time restraints of this project.

Each gestureRecognizer is initiated in the ViewController. When a gesture is performed, the matching gestureRecognizer is invoked. The gestureRecognizer then takes the location point of the touch and determines which button or grid area contains that point. Then the gestureRecognizer can decide what command is being performed and call the appropriate methods.

The location of the grid areas and buttons are defined by rectangles being set at the corresponding location to the overlay (See Figure 5.6 below for the settings):

```
//Buttons

bttn1 = CGRectMake(0, 0, 256, 140);

bttn2 = CGRectMake(256, 0, 170, 140);

bttn3 = CGRectMake(426, 0, 170, 140);

bttn4 = CGRectMake(596, 0, 170, 140);

//Grid Area

//Row 1

grid1 = CGRectMake(516, 140, 258, 294);

grid2 = CGRectMake(516, 434, 258, 294);

grid3 = CGRectMake(516, 728, 258, 294);

//Row 2
```

```
grid4 = CGRectMake(258, 140, 258, 294);
grid5 = CGRectMake(258, 434, 258, 294);
grid6 = CGRectMake(258, 728, 258, 294);
//Row 3
grid7 = CGRectMake(0, 140, 258, 294);
grid8 = CGRectMake(0, 434, 258, 294);
grid9 = CGRectMake(0, 728, 258, 294);
```

Figure 5.6 - Code for setting the coordinates of the button and grid areas to match up with the overlay.

5.6.4 Graphics

To quickly and efficiently create the graphical component for the prototype two different methods were used.

5.6.4.1 Method 1

For testing which required the participant to read a diagram either aurally or with sight (Refer to section 5.1.2.1 Part 1, and 5.1.2.2 Method 1), a number of jpg images were used. The images represented the entire diagram at different levels. Each image filled up the entire screen of the iPad and was only displayed when the corresponding navigation commands were entered into the system.

When the user changes to a different location, a series of if, elseif and else statements determine and set the image to be loaded (See example code in Figure 5.7 below).

```
if([curSession getZoomArea1] == 0){
  [curSession zoomInToArea:[curSession getArea:[gesture locationInView:self.view]]];
  if ([curSession getArea:[gesture locationInView:self.view]] == 2){
        myImageName = [NSMutableString stringWithFormat: @"image3.jpg"];
```

```
        newImage = TRUE;
    }
    else if ([curSession getArea:[gesture locationInView:self.view]] == 5) {
        myImageName = [NSMutableString stringWithFormat: @"image4.jpg"];
        newImage = TRUE;
    }
    else if ([curSession getArea:[gesture locationInView:self.view]] == 6) {
        myImageName = [NSMutableString stringWithFormat: @"image16.jpg"];
        newImage = TRUE;
    }
    else{
        myImageName = [NSMutableString stringWithFormat:@"image17.jpg"];
        newImage = TRUE;
    }
```

Figure 5.7 - Example of code for setting images

If a new image has been set (newImage = True), then the image will be loaded into the view

5.6.4.2 Method 2

For the prototype testing which required entering new objects into the system (Refer to Section 2.1.2.1 Part 2), only a simple diagram consisting of the object name and lines between the objects was displayed (Refer to Figure 5.8). The graphics were created by using the built in label function of the iPad SDK and the Core Graphics Framework. In order to quickly build the prototype, the labels were defined in the Interface Builder (a Graphical User Interface that allows you to drag and drop controls onto the interface). This means that the number of objects is limited to the number of predefined labels.

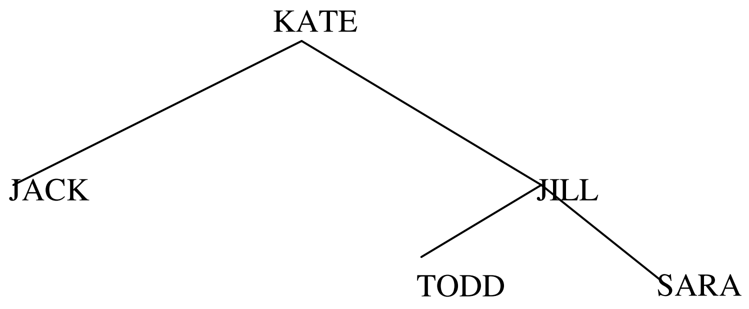


Figure 5.8 - Example: of how the graphics for method 2 appears

5.6.5 Sound

Simple audio sounds were integrated into the systems to provide the users with extra information. The SimToolkitGeneralBeep.wav audio file is played when the relocate or find commands are performed to let the user know the system is searching. The sound sounds similar to a beep or chime. The Tock.wav audio file is played for all other commands to let the user know when a gesture has been recognized. Tock.wav sounds similar to the sound of pushing a button. Both sound files are found by default on Apple systems.

5.6.6 Speech Recognition and Text to Speech

While Apple does have a speech recognition and a text to speech API for iOS4, it is unfortunately private and developers are not able to make use of this functionality at this time. In order to recognize voice commands, speech recognition must be possible and so alternative for the prototype was found. A bundled iOS library was used to provide the speech recognition and the text to speech capabilities. This product is called OpenEars which is a free open-source product that makes use of CMU Poketsphinx, CMU Flite and MITLM.

Pocket sphinx is an existing free speech recognition ToolKit produced by Carnegie Mellon University. MIT Language Modeling (MITLM) toolkit is a set of tools which estimates statistical n-gram language models for speech recognition. CMU Flite, another Carnegie Melon project, is a speech synthesis engine developed for running on small embedded machines.

The speech recognition system can support up to a 3000 word grammar. Although this option doesn't have the highest accuracy or a large grammar, it is the most viable solution for creating a prototype. In order to improve accuracy of the prototype, a small dictionary was created to work specifically with the prototype. The number of voices was also limited and only came with 8 voices. However, literature indicates that it should be possible to change the voices and the speed of the voices.

PocketSphinx takes a relatively long time to load and initialize. For this reason it is loaded as soon as the prototype starts up. The speech recognition is therefore is only used when needed by pausing the PocketSphinxController using the resumeRecognition and suspendRecognition methods as provided by the OpenEars API.

The system is unable to distinguish between it speaking and the user speaking. For this reason the system cannot be providing output at the same time it is listening for input. In order to prevent this, the system only listens for voice commands when it has been invoked by a gesture (as opposed to always listening for voice commands). The system must also wait till it is done speaking before it starts listening (See figure 5.9 for example code).

```
//set the voice recognition string to empty

[curSession setVoiceRecString:[NSMutableString stringWithFormat: @"NULL"]];

//Change text-to-speech (ask the user what the diagram name is)

[self.mySpeaker say:[NSMutableString stringWithFormat: @"What is the Diagrams Name?"]];

//wait until the system has finished talking

while ( ([curSession getSessionStarted] == FALSE) && [theRL runMode:NSDefaultRunLoopMode
beforeDate:[NSDate distantFuture]]);

//start listening for the user to speak/finish speaking

[self.myPocketSphinxController resumeRecognition];
```

```
//keep listening until the voice recognition string is no longer empty

    while ( ([[curSession voiceRecStringIs] isEqualToString: @"NULL" ]) && [theRL
runMode:NSDefaultRunLoopMode beforeDate:[NSDate distantFuture]]);
```

Figure 5.9 - Example code for waiting till speaking is complete until allowing voice recognition.

The output for text to speech is dependent on the defaults listed in the template and the values provided by the user. Below are examples of scripts used by the system to formulate the output for specific commands (See section 7.5.1 for a complete listing of the command set).

1. Obtain a diagram description: “[diagram description]. There are [number of objects] number of objects in the diagram. They are located in grid areas [the grid area numbers that contain objects].” The user defines the diagram description when he or she creates a new diagram. The number of objects and the area numbers that contain objects are calculated by the system.

2. Loading a new diagram: “Welcome, there is one diagram in the system. The name of the diagrams is [diagram name]. Do you want to load this diagram?” The user defines the diagram name when he or she creates a new diagram.

3. Adding a new object: “What is the object’s [first attribute]?” System waits for answer. “ You said [answer] is this correct?” System waits for “Yes” or “No” and repeats the previous question if “No” is the answer. “What is the object’s [second attribute]?” System waits for answer. “You said [answer] is this correct?” The system waits for “Yes” or “No” and repeats the previous question if “No” is the answer. The questioning continues until values for each attribute have been added. The available attributes are defined in the template.

4. Reading the relationships of an object: “[Primary Object name] [relationship name] [another object name].” If the user selected to list the locations, the system would also read “located at [zoom 1 grid] and [zoom 2 grid] and [zoom 3 grid].” The default relationship name is defined in the template. The user defines object names when creating the diagram.

5. Reading the attributes of an object: “[object type] is [object name]. The attributes are: [attribute 1 type] is [attribute value], [attribute 2 type] is [attribute value]”. Repeat until all the attributes have been read. The object type and attribute types are obtained from the template. The object name and attribute values are defined by the user.

5.6.7 Database

To provide the database platform, SQLite (Hipp, Wyrick and Company, Inc.) was chosen. This free software library allows one to run a transactional database engine directly on their device.

5.7 SPECIFIC PROTOTYPE DESIGNS

To evaluate the usability and viability of a tool which would use voice, touch and an overlay to allow users who are visually impaired to read and create diagrams, four separate prototypes were built for evaluation purposes. These prototypes are the:

1. Reading Prototype,
2. Creating and Editing Prototype,
3. Visual Representation Prototype 1, and
4. Visual Representation Prototype 2.

5.7.1 Command Set

The following command set was developed based on the command requirements defined in Chapter 3 (Refer to section 3.2), findings from the overlay testing (Refer to section 4.4), and creating a mapping between the command and the gesture. Below is a list of the commands and the mappings of the commands.

Change Between Read and Edit Modes

Change mode – single tap the mode button. Changing modes is an important task because it facilitates the command set available to the user. Since it is a command which does not perform a function on the diagram itself, it needs to be separated from the diagram area (grid area). A single tap was chosen because it is the easiest gesture to perform.

Read Diagram

Read overview of diagram – Long press on any grid area. This command is specific to the current zoom level of the image and only returns an overview of the ‘viewable’ diagram. For example when at zoom level one, the entire diagram is summarized while at zoom level three, only the objects in the grid areas at that location would be summarized. The command returns the number of viewable objects and the grid areas the objects are located at. At zoom level one the command will also return the diagram’s name and type.

Read objects located in a grid – single tap a grid area. The single tap was chosen because the assumption has been made that in navigation, a user would want to quickly tap grids to find out what object is there or to confirm an object is there.

Read objects and their locations located in a grid – double tap a grid. This command is the same as “read objects located in a grid” except it also returns the location of objects. The double tap was selected because this command returns more information, and more specifically location information.

Read objects and attributes of objects located in a grid – two finger tap a grid. The two finger tap was chosen because the command is somewhat similar to what is being returned in “Read objects located in a grid”, except it is also returning attributes (more information). An extra finger is added to the tap to represent more information.

Read objects, attributes and locations of objects located in a grid – two finger double tap. Again, this is similar to the above command (Read objects and attributes of objects located in a grid) so a two finger tap was selected. It is also returning location information, so an extra tap to signify location information was used.

Read objects and relationship of objects located in a grid – horizontal swipe in a grid area. This gesture was chosen because it was an easy gesture to perform and the swipe motion can be compared to drawing a line between two objects.

Read objects, relationships and locations of objects located in a grid – horizontal two finger swipe. This command is the same as “read objects and relationships” except that it also returns the locations. Since it returns more information than the first command, the commands were kept somewhat similar where an extra finger means extra information.

Zoom into a grid – Pinch in. Pinch in was selected because it represents going into the grid.

Zoom out of grids – Pinch out. Pinch out was selected because it represents moving out of the grid.

Relocate – single tap the Talk button. Speak the object name when prompted. The command will take you to zoom level 2 where the object is located. Note: “go home” will return you to the main view of the diagram. A button was selected to perform the command because it is invoking voice recognition and because the command does not utilize zoom level or grid location information. A single tap was selected because it is the easiest gesture.

Search – double tap speech button, speak object name or an attribute name when prompted. A list will be returned providing all the names of the objects which meet the search criteria along with the objects location. The talk button is used since this command also invokes voice recognition. Since the command also returns more information, including locations, an extra tap was added.

Edit Diagram

Add object along with its attributes and relationships – single tap any grid. The system will ask for each of the attributes and the relationships. The system automatically positions the objects in the diagram. Again, the single tap was chosen because it is the easiest gesture to perform. Even though this function invokes voice recognition, the gesture is performed in any grid area to enforce in the user’s mind that he or she are indeed putting the object into the diagram.

Modify object’s attributes – single tap talk button and follow the prompts. If you change relationships here, it automatically updates the diagram. The talk button was chosen to create separation between the adding and modifying gesture areas and because modifying also invokes speech recognition. Single tap was chosen because it is the easiest gesture to perform.

Load Existing Diagram – If you are just starting the program it will ask you if you want to open an existing diagram when there have already been saved diagrams. Answer: Yes

Create New Diagram – shake the iPad. A shake was chosen because it is a deliberate action which is different than all the other gestures. It also has the same effect as an etch-a-sketch for those who may have used one (shake the screen to make the picture disappear so you can make a new picture). The user is required to list a name and description by following the system prompts and then use the scroll buttons to select a diagram type.

Scroll buttons - To use the scroll buttons, tap the up or down scroll buttons to go into the list and come back through the list. Once the item to be selected is found, perform a 'long press' in either of the scroll buttons. The scroll buttons were designed for navigating through lists. Single tap and long press were chosen because they are easy and because the gestures which can be done inside a button are limited. A single tap is faster than a long press so it makes sense to use the single tap for the action which can occur multiple times (move iteratively through each item in a list).

5.7.2 Prototypes

For evaluation purposes, 4 prototypes were built. They are:

1. Audio and Graphical Reading Prototype: reading a diagram using the commands to obtain audio and/or graphical output. This prototype was for evaluating usability as discussed in Section 3.5.
2. Creating and Editing Prototype: automatically places objects created by the user into diagrams.
3. Graphical Representation Prototype: displays graphical diagrams under the overlay for reading with vision only. This prototype was specifically built to evaluate the visual representation and ensure the system can be easily utilized by sighted users (refer to section 3.1).
4. Audio only Reading Prototype: reading a diagram with use of commands to only obtain audio output.

All of the prototypes listed above do not have any data logging or data capturing capabilities. All data capturing is performed manually by the researcher.

5.7.2.1 Audio and Graphical Reading Prototype

Purpose

This prototype was built to see how participants use the system handling for reading objects, their attributes and their relationships in a diagram.

Functionality

The Reading prototype only contains functionality for reading diagrams. The command sets that are functional are the Read Diagram and Load Existing Diagram command sets. No functionality for creating or editing the diagrams is available.

Setup

The prototype is loaded with an organizational diagram (Refer to Appendix D 11.1) which has 40 objects. The database was manually populated to hold the needed information about the diagram (Refer to Appendix B for database schema). Since the graphics for this prototype do not change, the graphics were provided by using static .jpg images (For a more details see 5.6.3.1 Graphics Method 1).

The voice recognition system used a small dictionary of 10 words (Refer to Appendix B). These words were chosen based on the tasks that would need to be completed. The dictionary was kept as small as possible to increase the accuracy of the voice recognition engine.

5.7.2.2 Creating and Editing Prototype

Purpose

This prototype was built to see how users respond to the system handling placement of objects in a diagram.

Functionality

Each time a user creates a new object (Refer to Section 5.6.1 for the list of commands), the system automatically places the object into a location which is optimal for a visual audience.

Setup

A basic algorithm was used which calculates the objects location based on their parent node and how many children are under the parent (See figure 5.10 for the code).

```
-(NSInteger)positionObject:(DiagramObjects *)myObject x1:(NSInteger)xend x2:(NSInteger)xstart ycoord:(NSInteger)y{
        NSInteger x = (ceil((xend - xstart)/ 2))+ xstart;
        [self assignZoomLevels:x ycor:y obj:myObject];
        y = y+1;
        NSMutableArray *myChildren = [[NSMutableArray alloc]init];
        myChildren = [self getChildren:myObject];

        if ([myChildren count] > 0) {
                for (int i = 0; i<[myChildren count]; i++) {
                        NSInteger xendSend = ((xend - xstart)/[myChildren count])*(i+1) + xstart;
                        NSInteger xstartSend = xendSend - ((xend - xstart)/[myChildren count])+1;
                        [self positionObject:[myChildren objectAtIndex:i] x1:xendSend x2:xstartSend ycoord:y];
                }
        }
}
```

Figure 5.10 - Code for assigning objects to a supervisor (adapted from http://www.uta.fi/~jl/pgui03/project/treedraw.txt)

It should be mentioned that this code was specifically written for use with the prototype and the organizational diagram (Refer to Appendix D 11.2) that uses a vertical hierarchy top-down layout. The algorithm would need to be modified before it could work with the remaining diagram layouts. The algorithm only supports placing the start node (first object) in the centre of the top row.

Since the addition of objects to the diagram would involve inserting objects in an order that is at the discretion of the participant, using the static .jpg images for graphics was not feasible. In order to produce a quick prototype, yet provide the user with some visual output where applicable, the line and label solution was used (Refer to section 4.7.3.2). As mentioned earlier, this graphical representation limits the number of objects that can be displayed. For testing this prototype, the objects were limited to 10 objects, which is the number of objects participants are asked to add to the diagram.

The voice recognition system used a dictionary of 36 words (Refer to Appendix B). These words were chosen based on the tasks that would need to be completed. The dictionary was kept as small as possible to increase the accuracy of the voice recognition engine.

5.7.2.3 Graphical Representation Prototype Design

Purpose

The prototype was designed to only display graphics at the three different zoom levels. This will allow participants the ability to focus on the visual aspect of the graphics when they are being viewed behind the overlay.

Functionality

Since the prototype is only for viewing the diagram graphics at different zoom levels, only the zoom in and zoom out commands are available.

Setup

To display the images, the method of using static .jpg images was used as described in section 5.6.3.1. The prototype displays one ER-Diagram (Appendix F) and one Organizational Diagram (Appendix F) separately.

5.7.2.4 Audio only Reading Prototype Design

Purpose

The purpose of this prototype is to allow participants to use sight for a task that requires sight but not provide them with the graphical diagram information as provided in the Reading Prototype. This will allow participants the ability to listen to the diagram installed in the system and draw the matching diagram.

Functionality

The design of this prototype was a modified version of the Reading Prototype. The only functional difference between the two prototypes is that this prototype does not display any graphics. This prototype uses the same command set as the Reading Prototype.

Setup

This prototype is loaded with the same database for the Organizational Diagram as the Reading Prototype but the dictionary for the Visual Representation Prototype design is much larger at 83 words (Refer to Appendix B), which covers all the attributes in the diagram. For the ER-Diagram, a different database was used which manually had the entries to display an ER-Diagram (Refer to Appendix G, 14.2). This diagram had a custom dictionary of 34 words (Refer to Appendix B).

CHAPTER 6

6 EVALUATION AND RESULTS

The main testing took place after adjustments were made to the gestures selected as a result of stage one testing. The main testing is a comprehensive test of the entire system including the command set and the comprehension of the grid system.

The system was split into three separate evaluations. This chapter will list the questions to be answered by the evaluations, describe the design of the evaluations and list the results for that evaluation. The evaluations will be presented in the following order:

General Usability Study Prototypes

1. Part 1 – Reading: testing the system to see if participants can read a diagram
2. Part 2 – Creating: testing the system to see if participants can create and edit a diagram

Additional study prototypes

1. Graphical Representation Prototype - testing to see if the sighted can read the diagrams visually,
2. Audio only Reading Prototype - testing to see if the sighted are able to reproduce a diagram by using information provided by a prototype.

As defined by ISO9241-11:1998(E), usability is the “Extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use”. One can therefore measure usability by:

Effectiveness – “accuracy and completeness which users achieve specific goals”(ISO, 1998).

Efficiency – “resources expended in relation to the accuracy and completeness with which user achieves goals”(ISO, 1998).

Satisfaction – “freedom from discomfort and positive attitudes towards the use of the product”(ISO, 1998).

6.1 GENERAL USABILITY STUDY

In order to determine the usability of the system for both sighted and visually impaired persons, the following research items were looked at:

1. effectiveness,
2. efficiency, and
3. satisfaction.

The study was also interested in obtain suggestions from participants

6.1.1 General Usability Evaluation Design

6.1.1.1 Participants

VATgram’s usability was evaluated via user testing with 5 simulated visually impaired participants (who were blindfolded), 5 visually impaired participants and 5 sighted participants. Simulated visually impaired participants were used because of the difficulty in finding visually impaired subjects. This techniques was also used by Califf, Goodwin and Brownell (2008); and Schneider and Strothotte (2000). It should also be mentioned that the results obtained from the simulated visually impaired subjects are similar to someone who recently became visually impaired (McGookin et al, 2008). Each session lasted approximately 1 – 2 hours and had two parts. Part 1 involved reading the diagram and Part 2 involved creating/editing a diagram.

Participants were given brief training on using the system. Using the think-aloud method (a method where participants will think out loud so the researcher can ‘hear’ their thoughts), users perform a number of tasks. The tasks are split into two categories; reading diagrams and creating diagrams. Participants were directed that the researcher could provide them with a reminder of the commands or a re-explanation of how the system worked at any time.

After the session, a post-testing paper-based questionnaires (refer to Appendix E) was conducted to determine users' perceptions of both prototypes. Sighted participants answered the paper based questionnaire on their own. Blind participants were read the questions by the researcher and the researcher filled in their answers on the questionnaire form. The questionnaire asked demographic questions as well as satisfaction questions that will be discussed further in section 6.1.1.2.

6.1.1.2 Measures of Usability and Methods for Obtaining Them

During the session, the researcher observed the process and took notes by hand for both part 1 and part 2 together. Below is a listing of the measures and how they were obtained.

1. Effectiveness was measured by the following methods:
    a. Did the participant successfully complete the task? The researcher recorded her observation.
    b. What was the number of errors by the participant? The researcher observed the number of errors and listed a count.
    c. What was the number of voice recognition errors by the system? The researcher observed the number of errors and listed a count)
2. Efficiency was measured by the following methods:
    a. Was an optimal set of commands used? The researcher recorded the ratio of how many commands were used by the participant and divided this by the most optimal number of commands.
    b. How many times did the participant need a review or explanation of the commands? The researcher recorded a count of the times she was asked for help.
3. Satisfaction was measured by the following methods:
    a. What was the participant's satisfaction with ease of use for the system? Each participant was asked questions via a questionnaire. The researcher asked and recorded the questions for the visually impaired participants on the questionnaire form while the sighted and blindfolded participants read and answered the questions on their own.

4. Participants Suggestions and Observations
    a. Were there any suggestions or comments from the participants? The questionnaire asked the participant for improvement suggestions and general comments. The researcher asked and recorded the questions for the visually impaired participants on the questionnaire form while the sighted and blindfolded participants read and answered the questions on their own
    b. Were there any interesting occurrences during the session? The Researcher made observations and recorded items from participants 'thinking aloud'.

6.1.1.3 Part 1 of General Usability Study - Reading Prototype Methodology

Participants were given the Reading Prototype to use. To determine the ease of use and readability of the diagram the users were asked questions that required them to perform a specific task. The users then needed to use the prototype in order to find the answers to the questions. Tasks were chosen to best represent the information a user would be visually looking for when reading a diagram. This includes finding information about specific objects, attributes and relationships as broken down in Table 5.1.

The following tasks were selected because they obtain the main visual information of a diagram as described in section 5.1. This includes information about an object, its attributes and its relationships.

Much like using commands in Microsoft Office, there are a number of different commands that could be used to solve the same task. Below is the list of tasks the participants were asked to perform and the most efficient command that can be used to complete the task.

1. Determine how many people are in the diagram. Once the diagram loads, it automatically gives an overview of the diagram. If the participant heard and understood, they would not need to perform any commands.
2. Determine attributes. Participants will be asked to name the roll, and department of Susan, Jill and Ted. This task can be completed by:
    a. using the 'relocate' command to relocate to the person (and listen to their grid area location);
    b. perform a two finger tap on the grid area obtained from the above step.
3. Determine relationships. The participant will be asked the following questions:

a. How many people does Sam supervise? This task can be completed by:

    i. Using the 'relocate' command to relocate to Sam (and listen to his grid area location);

    ii. Perform a one finger swipe on grid area obtained from above step.

b. Who are all the people supervised by Lilly? This task can be completed by:

    i. Use the 'find' command to find Lily. This returns all of her subordinates.

c. Who works in Finance?

    i. Use the Find command on Finance. This returns a list of all the objects who have an attribute that has a value of Finance.

6.1.1.4 Part 2 of General Usability Study – Creating Prototype Methodology

Participants then used the Creating and Editing Prototype to create an organizational diagram. Participants were first given a scenario of people and relationships in a simulated business (Appendix D 11.2). They were given the task of creating a diagram of the organization of that business. The tester repeated the company information when asked by the participant. To create the diagram, participants performed the following tasks:

The following tasks were selected because they allow one to enter the main visual information of a diagram into the system as described in section 3.2. This includes entering information about an object, its attributes and its relationships.

1. Create a new organizational diagram file
2. Create 10 persons with the following attributes
    a. name
    b. title
    c. department
3. Create the appropriate relationships
4. Change a person's supervisor
5. Change a person's title

6.1.2 General Usability Results

6.1.2.1 Demographics

Participants were asked to complete a questionnaire. The first eight questions were demographic questions. The results from the demographic questions are compiled below in Tables 6.1, 6.2 and 6.3.

	Visually Impaired Participants				
Participant	1	2	3	4	5
Gender	m	f	F	m	m
Age group	45-54	45-54	18-24	45-54	45-45
Sight Abilities	totally blind	none	retinopathy prematurity - sees around big spots, cannot see detail	blind	can see light and dark and some other shades, shapes and motion in the right lighting
Age of sight loss (becoming legally blind)	birth to 1	birth to1	birth to 1	20-29	20-29
Diagram experience	tactile and listening to diagrams.	tactile and people reading	all	all	all
IPad/iPod/iPhone experience	yes	none	yes	yes	no
Touchpad experience	yes	none	yes	yes	yes

Table 6.1 - Demographics Visually Impaired

	Blind folded Participants				
Participant	1	2	3	4	5
Gender	m	f	f	m	f
Age group	25-34	25-34	18-24	15-18	25-34
Sight	normal	normal	normal vision with	normal vision with	I have normal vision with use

Abilities			occasional use of glasses	the use of glasses	of glasses
Diagram experience	Visual diagrams	Visual diagrams	Visual diagrams	Visual diagrams	Visual diagrams
IPad/iPod/iPhone experience	yes	yes	yes	yes	yes
Touchpad experience	yes	yes	yes	yes	yes

Table 6.2 - Demographics Blindfolded

	Sighted Participants				
Participant	1	2	3	4	5
Gender	F	m	m	f	f
Age group	45-45	55-64	45-54	45-54	25-34
Sight Abilities	normal with glasses	normal	normal	normal with glasses	normal with glasses
Diagram experience	All	None	Visual	visual	all
IPad/iPod/iPhone experience	no	very little	no	no	yes
Touchpad experience	yes	very little	no	no	yes

Table 6.3 - Demographics Sighted

6.1.2.2 Effectiveness

To determine effectiveness, accuracy and completeness were measured in terms of whether the tasks were completed, what the error rates were and any voice recognition errors.

6.1.2.2.1 Completed Tasks:

There were only four instances, with three participants, of events where a participant was unable to complete the task correctly.

Task: Who does Sam Supervise? One blindfolded participant could not determine who Sam supervised. One sighted participant failed to return the correct answer.

Task: Move Anna to be supervised by Jack. A sighted participant did not complete the task. The participant added a new object instead of modifying an object.

Task: Change Barry's title to Assistant. The sighted participant, as mentioned above, did not complete the task. The participant added a new object instead of modifying an object.

6.1.2.2.2 Errors

Error rates varied between the different tasks. See Figure 6.1 below to see the average error rates for each task for Part 1, reading diagrams.

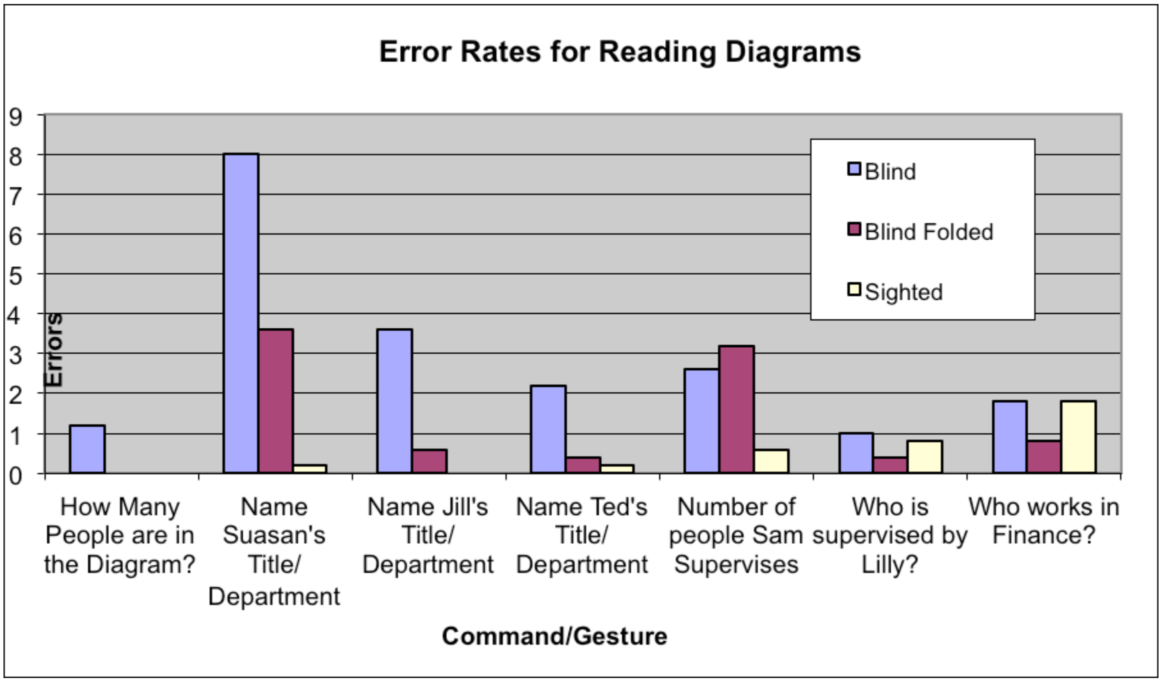


Figure 6.1 – Error rates for Part 1 (reading diagrams)

Figure 6.1 above indicates that the visually impaired had substantially more errors than the sighted and blindfolded individuals for the following tasks:

1. How many people are in the diagram?
2. Name Susan's Title/Department.

3. Name Jill’s Title/Department.
4. Name Ted’s Title/Department

More information can be gathered by looking at the number of errors per visually impaired participant for the tasks mentioned above. Refer to Figure 6.2, which displays the number of errors per task.

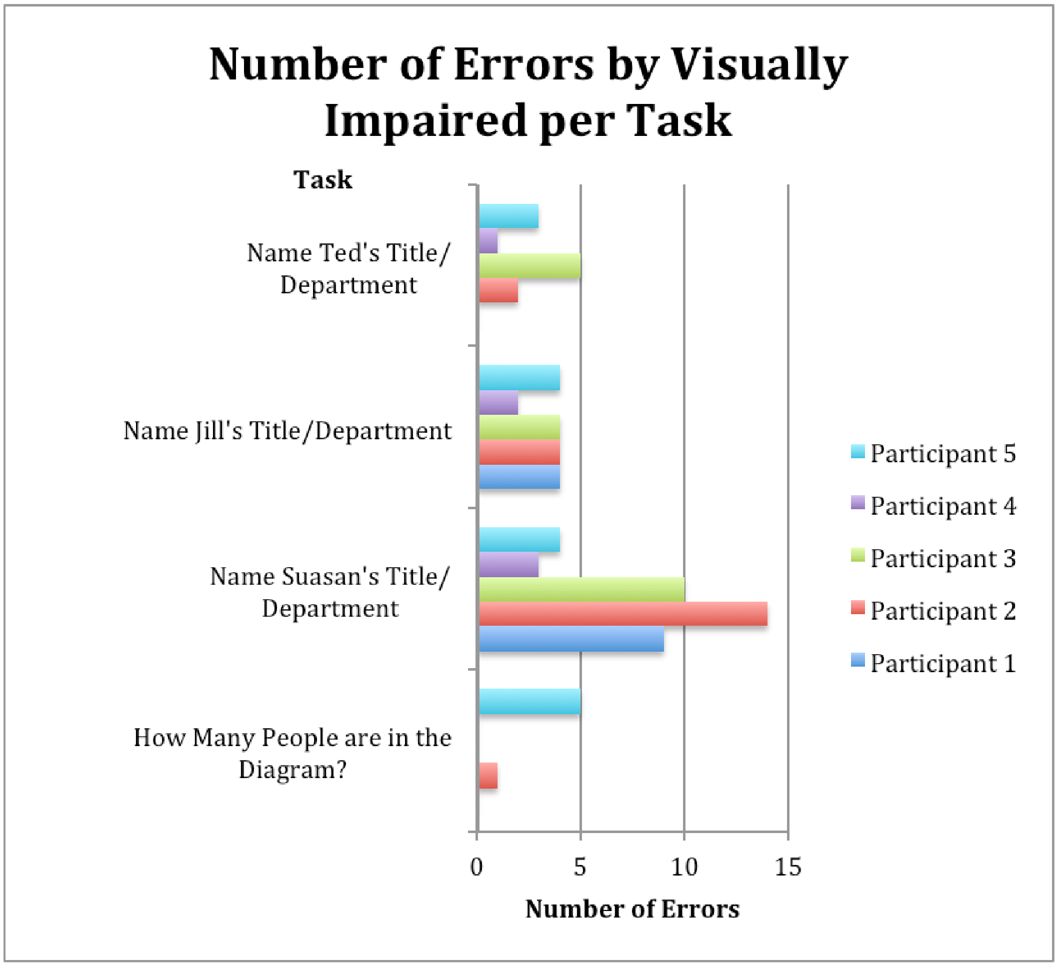


Figure 6.2 - Number of errors per visually impaired participant per task

On average, errors for creating diagrams were lower than that for reading diagrams. See Figure 6.3 which displays the errors per task for each participant group.

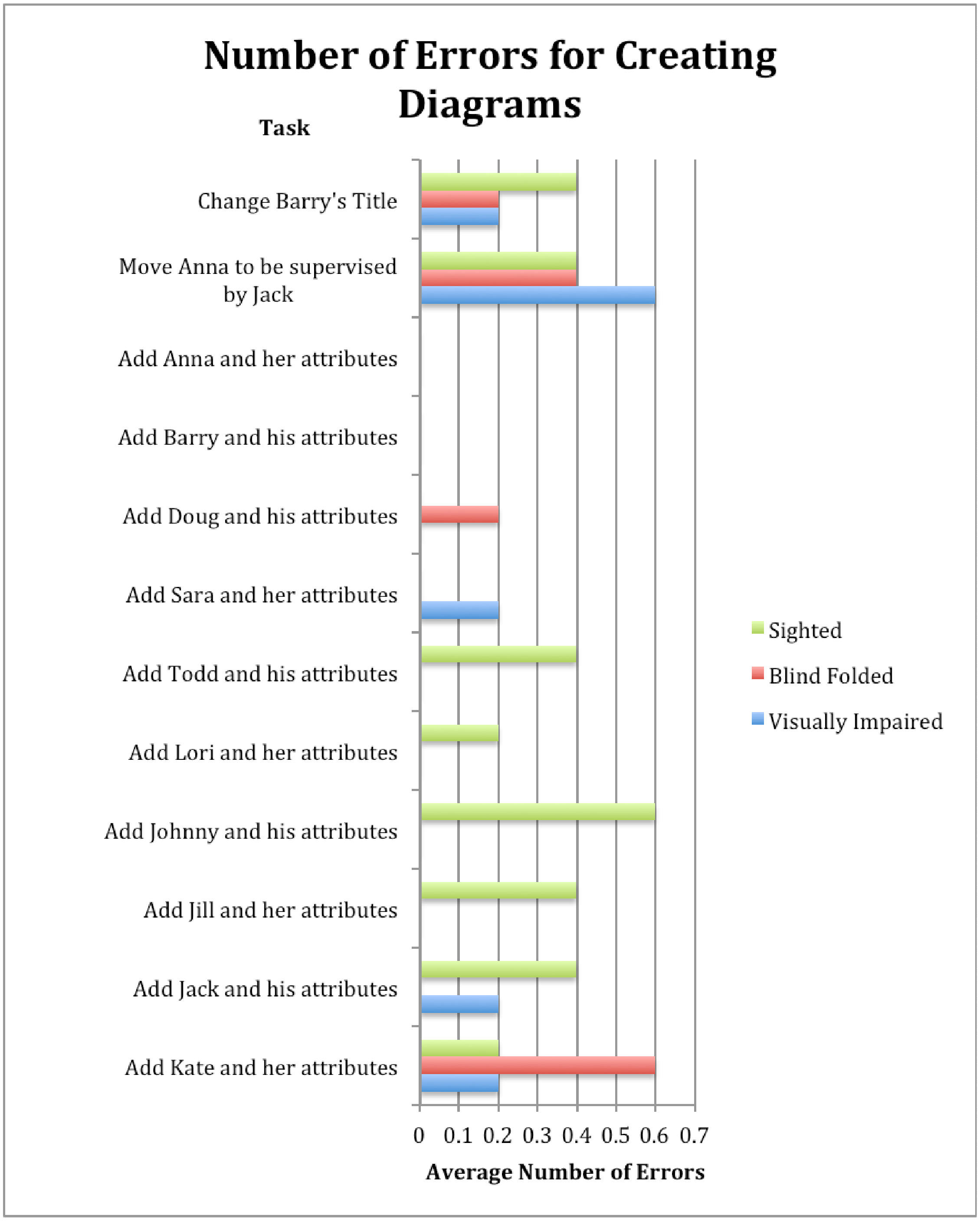


Figure 6.3 – Average number of errors per participant group per task.

Below are the average errors by participant type for each Part of the session. Creating/Modifying the diagram had a low error rate with the range of average errors being from

0 to 0.6 errors per participant group. Reading the diagrams had a range of errors being from 1 to 8 errors per participant group. (See Figure 6.4 below)

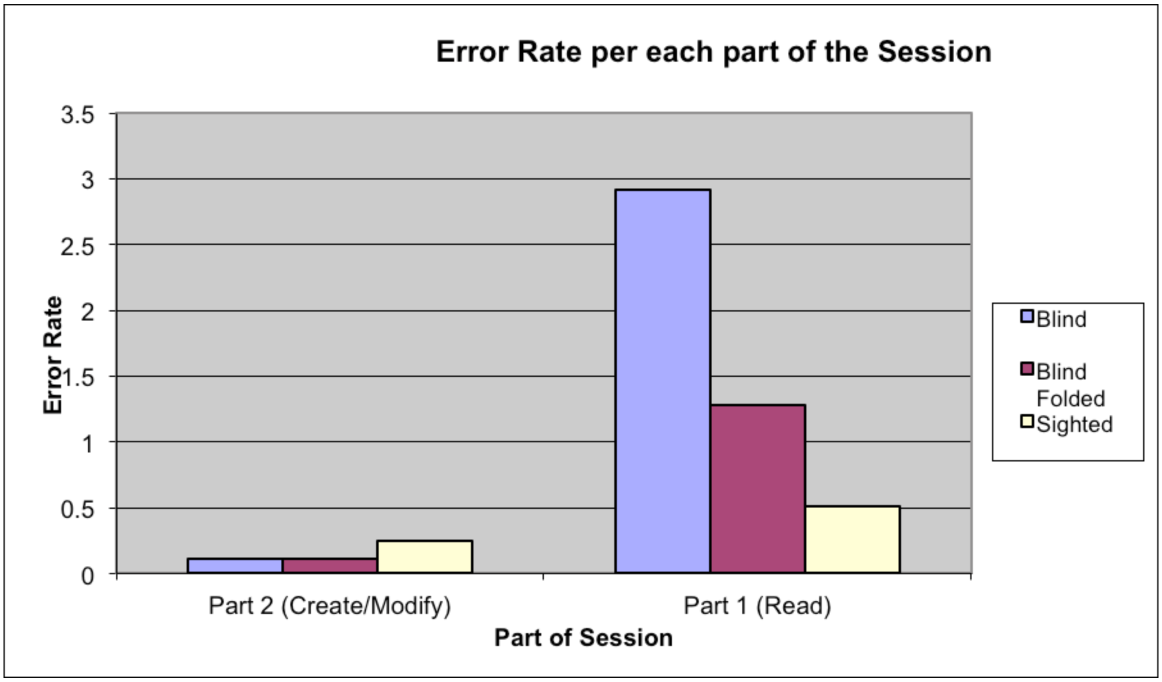


Figure 6.4 - Average Error Rate for each part of the session

6.1.2.2.3 Voice Recognition Errors

The number of times voice input was required in Part 1 was variable and dependent on the commands the participant decided to use. Voice input for Part 2 was more static. If the system was to recognize an input correctly every time, then all participants would have given voice input a total of 86 times each.

The lowest number of voice errors for Part 2 was 7 errors by a blindfolded male participant. The highest number of voice errors for Part 2 was 54 by a blindfolded female participant. Table 6.4 below lists the average number of errors for each sight group.

Sight Abilities	**Average Number of Errors/Participant for Part 1**	**Average Number of Errors/Participant for Part 2**
Sighted	1.6	15.6
Blindfolded	3.2	29.6
Visually Impaired	3.6	18.8

Table 6.4 - Average number of voice recognition errors per sight ability group

The average number of voice recognition errors for Part 2 was 1.7 times higher for female participants than it was for male participants. See Table 6.5 below to see the average number of voice recognition errors for each gender.

Gender	**Average Number of Errors/Participant for Part 1**	**Average Number of Errors/Participant for Part 2**
Male	2.7	16.5
Female	2.9	28.5

Table 6.5 - Number of errors by gender for each part of the general usability study.

The very last participant of the study mentioned that she had some experience with voice recognition. The voice recognition errors for her were 11 (well below the average number of errors). This was not a question the researcher thought to ask all participants; however, the question should have been asked.

6.1.2.3 Efficiency

6.1.2.3.1 Optimal use of commands

The number of commands that the participants used for each task can be compared to the number of optimal commands to be used. (Refer to section 6.1.1.3 for the list of optimal commands for each task). Table 6.6 lists the ratios for the average number of commands used by each participant group to the number of optimal commands that can be used for Part 1. While visually impaired and blindfolded participants could at best use the optimal number of commands, the sighted participants could skip the use of some commands and obtain information visually. The size of the diagram was too small at certain zoom levels to omit the use of all commands. For this reason, the ratios for some tasks completed by sighted participants will have a lower ratio of commands used to the optimal number of commands.

Task	Visually Impaired	Blindfolded	Sighted
How Many People are in the Diagram?	1.2:0	1.2:0	0:0
Name Susan's Title/Department	3.6:1	4.9:1	1:2
Name Jill's Title/Department	2.3:1	1.6:1	1:2
Name Ted's Title/Department	2.2:1	1.3:1	1:1.4
Number of people Sam Supervises	3:1	2.8:1	1.9:1
Who does Lily supervise?	1.8:1	1.5:1	1.6:1
Who works in Finance?	3.2:1	2.2:1	3.6:1

Table 6.6 - Ratio of the number of commands performed per participant type to the most efficient number of commands needed for Reading Diagrams (Part1).

The following tasks had ratios greater than 2.5 times for the average number of commands performed by the Visually Impaired and Blindfolded:

Name Susan's Title/Department,

The number of people Sam supervises

As well the Visually Impaired and the Sighted had ratios greater than 2.5 times for the task: Who works in Finance.

Tables 6.8, 6.9 and 6.10 show more detail regarding the tasks which have the greatest ratios as listed above. In each participant group there was a large variation in the number of commands they used per task. The largest differences can be seen in the visually impaired and blindfolded groups. The range of these differences is also displayed in tables 6.13, 6.14 and 6.15 below.

			Visually Impaired Participant				
Task	**Most Efficient number of commands**	**Range of number of commands used by participants**	**1**	**2**	**3**	**4**	**5**
Name Susan's Title/Department	2	10	2	12	12	5	5
Number of people Sam Supervises	2	13	7	2	15	2	4
Who works in Finance?	1	6	3	2	1	7	3

Table 6.7 - Number of commands used per task by the Visually Impaired

			Blind Folded Participant				
Task	**Most Efficient number of commands**	**Range of number of commands used by participants**	**1**	**2**	**3**	**4**	**5**
Name Susan's Title/Department	2	25	3	4	28	7	7
Number of people Sam Supervises	2	8	4	2	6	10	na

Table 6.8 - Number of commands used per task by the Blindfolded

			Sighted Participant				
Task	**Most Efficient number of commands**	**Range of number of commands used by participants**	**1**	**2**	**3**	**4**	**5**
Who works in Finance?	1	3	4	4	5	3	2

Table 6.9 - Number of commands used per task by the Sighted

Table 6.10 lists the ratios for the average number of commands used by each participant group to the number of optimal commands that can be used for Part 2 (Refer to section 6.1.1.4 for the list of optimal commands for each task).

Task	**Visually Impaired**	**Blindfolded**	**Sighted**
Add Kate and her attributes	1.5:1	1.2:1	1:1
Add Jack and his attributes	1.4:1	1.2:1	1.2:1
Add Jill and her attributes	1.2:1	1:1	1.4:1
Add Johnny and his attributes	1:1	1:1	1.6:1
Add Lori and her attributes	1:1	1:1	1:1

Add Todd and his attributes	1:1	1:1	1.2:1
Add Sara and her attributes	1.2:1	1:1	1.2:1
Add Doug and his attributes	1:1	1:1	1:1
Add Barry and his attributes	1:1	1:1	1:1
Add Anna and her attributes	1:1	1:1	1:1
Move Anna to be supervised by Jack	1.4:1	1.4:1	1.5:1
Change Barry's Title	1:1	1.4:1	1.5:1

Table 6.10 - Ratio of the number of commands performed per participant type to the most efficient number of commands needed for Creating Diagrams (Part2).

6.1.2.3.2 Number of times commands needed to be reviewed by Participants

Participants were allowed to ask the researcher to review the commands with them. However, the number of times one needs to review commands reduces one’s efficiency. Below is Table 6.11 that lists the average number of times participants asked to review commands.

Participant type	Average number of times commands were reviewed per participant
Sighted	4.4
Blindfolded	7.4
Visually Impaired	7.2

Table 6.11 - Average number of times commands were reviewed by the participant.

6.1.2.4 Satisfaction

The average rating of their entire experience by the visually impaired is an 8.8 out of 10. The blindfolded participants scored the Reading and Creating Prototypes together is a 7.2 out of 10 while the sighted participants scored the tools with a 6.6 out of 10.

When it came to ease of use, again the blind participants rated the tools higher than the blindfolded and sighted individuals. Two of the blind participants commented on how they liked the gesture to command mappings because they made sense and commented on how they liked having the overlay as it made it easier to place their commands and know where objects were.

Overall the prototype was rated as easy to use. The commands rated low on how easy they were to remember (See Figure 6.5).

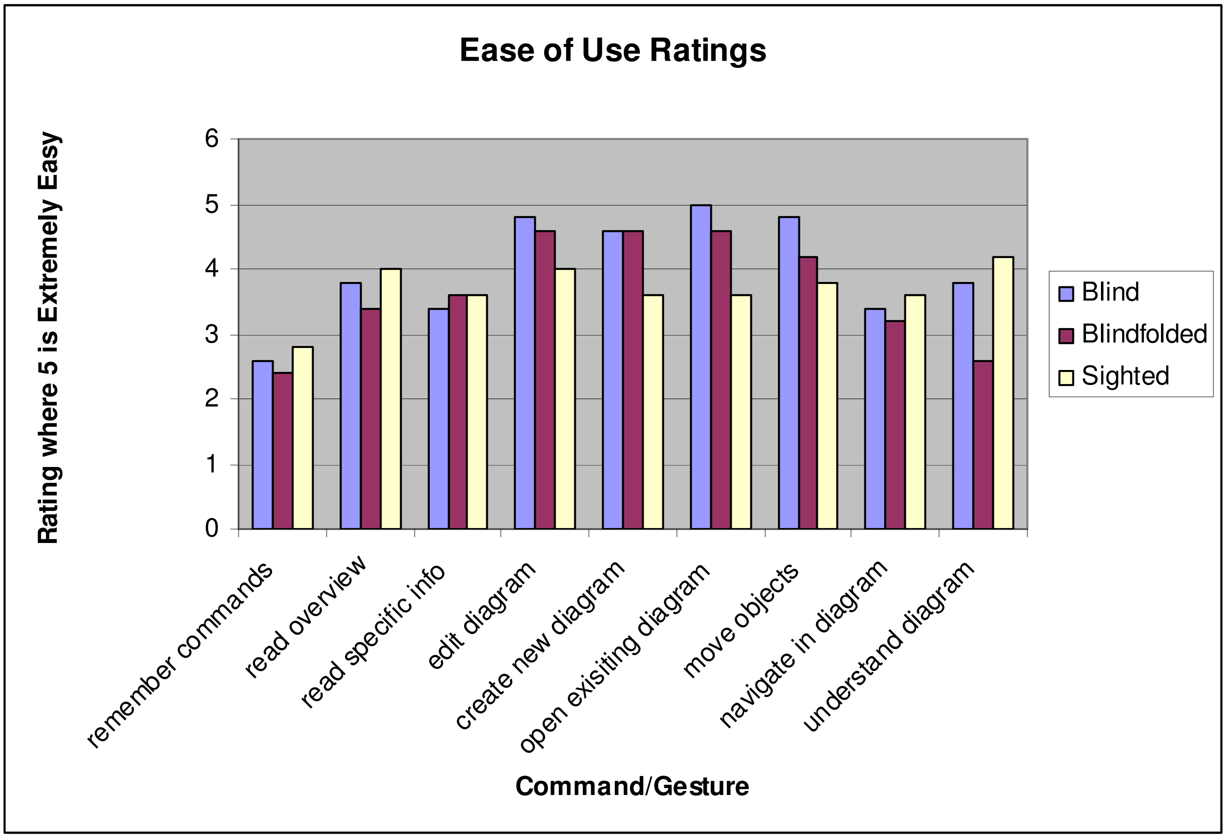


Figure 6.5 - Ease of performing each type of command rated by participants

On average, creating and modifying objects had extremely low error rates for all participants with less than 1 error (See Figure 6.4). Participants with the highest error levels (an average of 3 errors per person) are the blind participants and yet they were also the most satisfied with the prototype, whereas the sighted participants who have the lowest error rate (an average of less than 1 error per person) rated their satisfaction the lowest.

The questionnaire asked a general satisfaction question to determine if participants would use the system if a consumer product was made available. More than half the respondents said they would use the system (both parts 1 and parts 2).

Assuming that you needed to use a diagram in the future and you own an iPad would you use VATagrams? Why or Why not?			
Answers	**Visually Impaired**	**Blindfolded**	**Sighted**
Yes	2	1	1
Yes with conditions	3		2
No with explanation		3	1
Refrain from answering		1	1

Table 6.12 Answers to general satisfaction question: would you use VATagrams?

For the conditional Yes, participants were looking to:

1. A visually impaired participant wanted to share with sighted person
2. A sighted participant wanted to share with a visually impaired person
3. Import existing diagrams
4. Use it for specific relationship diagrams

For the explanation of the No's, one blindfolded participant indicated he needed more visual software; however, since he was blindfolded during the experience and didn't see the graphics, this answer is out of scope of the evaluation. Another blindfolded participant mentioned he would not use the tool because he wasn't sight impaired. One sighted participant found that the commands were too difficult to remember.

6.1.2.5 Participants' suggestions and Researcher's observations

Information was gathered from participants' suggestions and researcher's observations in order to identify areas of possible improvement.

6.1.2.5.1 Participant’s suggestions

Participant’s suggestions and comments were captured by the questionnaire. Table 6.13 lists the number of participants per participant type who disliked a specific feature. This question may identify areas where the system requires improvement.

Were there any features or functionalities in VATagrams that you disliked? If yes, what?			
Answers	**Visually Impaired**	**Blindfolded**	**Sighted**
Voice recognition	1	2	
Commands were difficult to use/precise		1	1
Amount of commands			2
If the scroll button functionality was reversed	1		
To have the search as 1 tap and the relocate as a double tap	1		
Reading the diagram	1		
Grid system	1		
Certain feedback from the system could be more specific	1		
Faster voice	1		
More natural voice	1		

Table 6.13 - Number of participants who disliked specific features of the program.

Table 6.14 lists the number of participants per participant type who would have liked a specific feature. This question may identify items which could improve current functionality.

Were there any features which you would have liked to have which were not already in the program?			
Answers	**Visually Impaired**	**Blindfolded**	**Sighted**
Help feature	1	1	
Yes/No button	1	1	
Use the program in portrait mode	1		

Something to allow me to calibrate the overlay	1		
Labeling [command] to be more descriptive	1		
Ability to have words spelled out by the screen reader	1		
For creating family trees – be able to show if people are deceased, divorced, had multiple relationships	1		
Ability to act like traditional tactile drawings where you can drag your finger over the images and the system tells you what is under your finger	1		
Voice prompt			1
Spell words as voice input if system doesn't recognize		1	

Table 6.14 - Number of participants who would have liked to have features which were not already in the program.

Table 6.15 lists comments provided by participants. This question may identify items which could improve current functionality.

Do you have any comments or suggestions about VATagrams?			
Answers	**Visually Impaired**	**Blindfolded**	**Sighted**
I would rather push buttons than use the voice control.	1		
Old x-ray sheets could be used for the overlays because they are a heavy plastic.	1		
It was difficult at first to remember the commands but then I started remembering the commands more because they're easy.	1		
I liked the App.	1		
The voice could be more natural	1		
Took awhile to get used to the screen sensitivity.	1		
Took a bit to get used to the voice recognition	1		

Table 6.15 - List of comments by participant type

6.1.2.5.2 Researcher's observations

One of the tasks was to find out how many people Sam supervised. Sam didn't supervise anyone. The system only reads existing relationships. Below is a summary of how the visually impaired and blindfolded participants worked through the task.

Visually Impaired:

1 person tried multiple different commands after using the read object and relationships command before deciding Sam supervised no one.

1 person said she thought Sam supervised no one but wasn't sure.

2 people knew right away that Sam supervised no one.

1 person said he was certain Sam supervised no one because he had accidently swiped another object and heard all the relationships and because he heard how it worked for an object who supervised others, he decided that Sam must not supervise anyone.

Blindfolded:

3 participants were not sure at first and tried a few other commands after the initial swipe.

1 knew right away.

1 was very confused and unable to answer the question.

When the sighted individuals used the prototype for reading, they only made use of the Relocate, find and zoom commands. When trying to complete tasks, they focused on the visual aspects of the diagram and did not make use of any auditory output.

6.2 GRAPHICAL REPRESENTATION PROTOTYPE

The General Usability testing was generic to sighted and non-sighted users. For this reason it did not focus on the usability of the graphical diagram by the sighted users as required and discussed in section 3.1. Testing the graphical representation prototype focuses on whether a diagram is usable in terms of user satisfaction by sighted individuals through the overlay.

6.2.1 Graphical Representation Prototype Design

This test was given in the context that a sighted person may be collaborating with a visually impaired person. Five sighted participants were chosen. Each testing session was about 30 minutes. Each participant was shown the following diagrams (Appendix F) and given brief training on how to zoom into the three different zoom levels using VATagrams:

1. Organizational diagram – The diagram had a top down structure with 15 objects. The attributes it displayed are: name, department and roll.
2. ER-Diagram – The diagram was user defined with 6 objects.

Participants were left to examine the diagrams at their own pace while they answered a series of open ended questions for each diagram (Appendix F).

The questionnaire asked participants to look at the diagram at zoom levels 1, 2, and 3 and answer whether the diagram was readable at each level, and then were asked three additional questions after doing this.

The researcher was expecting that participants would not be able to read the diagram at zoom level 1 and possibly not at zoom level 2. These questions were meant to guide the participants through the experiment because the real focus of the experiment is to answer the three follow up questions.

The questions that need answering are:

1. Was zooming in and out of the diagram helpful for reading the diagram? Why or Why not?
2. Were there any parts of the diagram which were confusing or difficult to read because of the overlay? If yes, please explain.
3. If you were working with a visually impaired person, can you see the diagram well enough through the overlay to help this person? Please explain in detail.

Below are the images (Figures 6.6, 6.7 and 6.8) depicting the ER-Diagram at the different zoom levels.

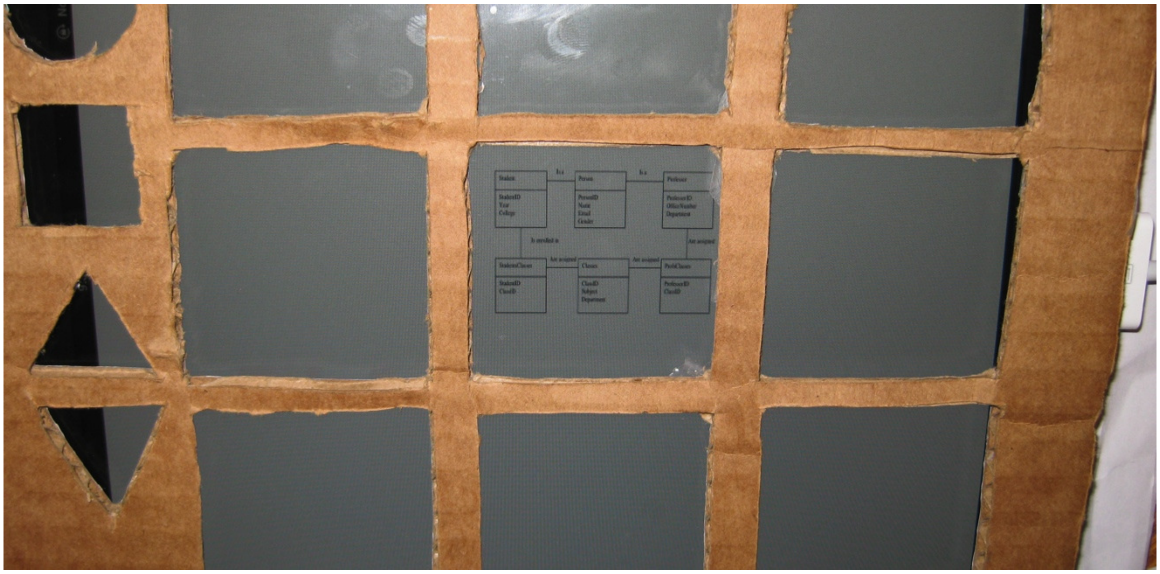


Figure 6.6 - ER-Diagram at zoom level 1

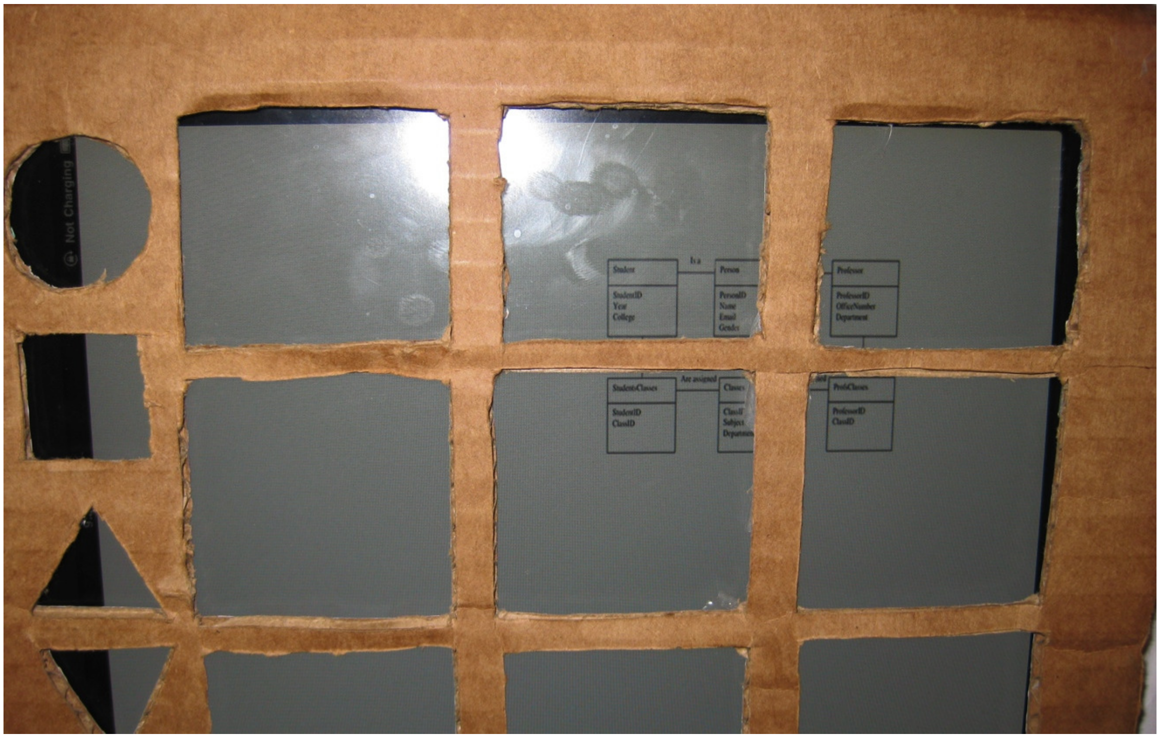


Figure 6.7 - ER-Diagram at zoom level 2

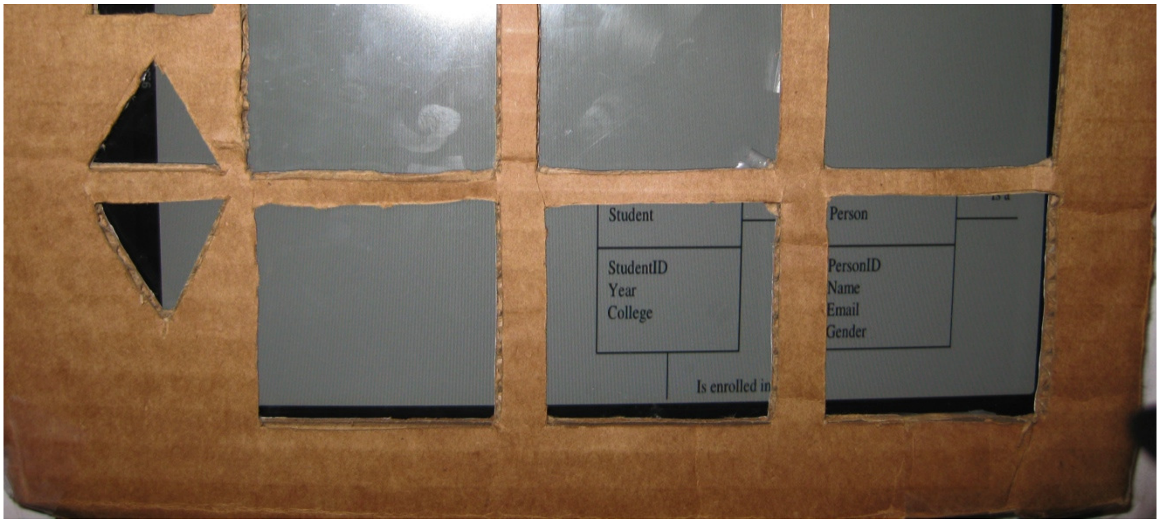


Figure 6.8 - ER-Diagram at zoom level 3

Below are the images (Figures 6.9, 6.10 and 6.11) depicting the Organizational diagram at different zoom levels.

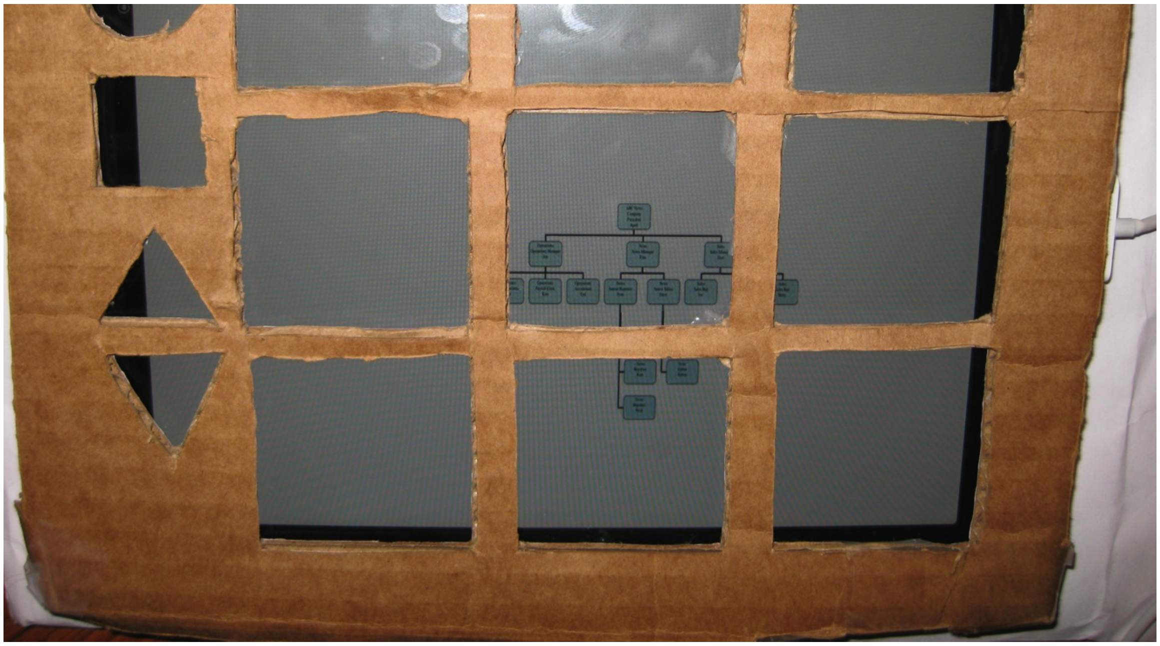


Figure 6.9 - Organizational diagram at zoom level 1

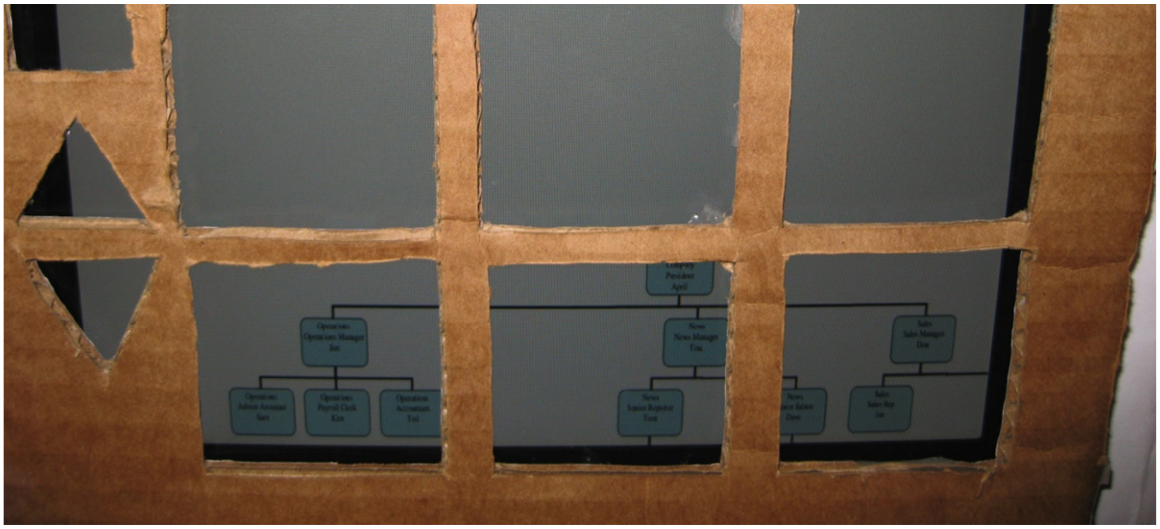


Figure 6.10 - Organizational diagram at zoom level 2

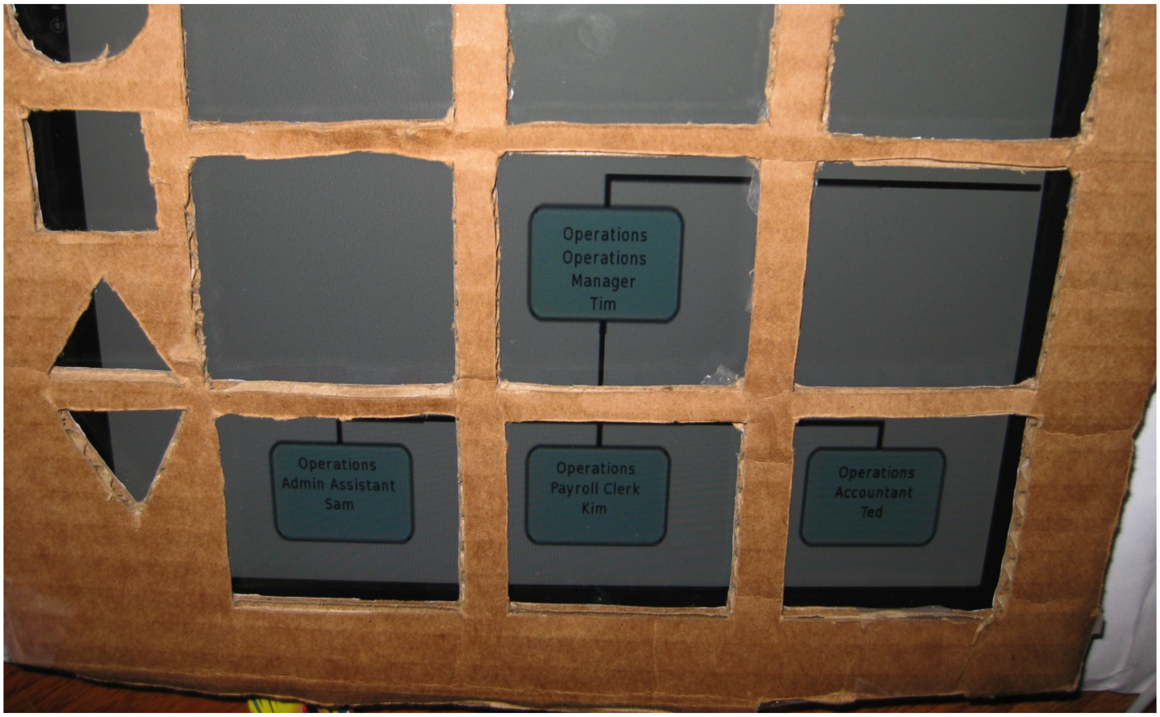


Figure 6.11 - Organizational diagram at zoom level 3

6.2.2 Graphical Representation Prototype Results

The results for Method 1 were entirely based on a questionnaire answered by participants. Below is a summary of each participant's answers.

Organizational Diagram:

At level 1, was the diagram easy to read? Why or Why not?

3 no because of small text size

2 qualified yes, readable except for the text in the diagram

At level 2, was the diagram easy to read? Why or Why not?

4 qualified yes, readable but text is still small and can only see part of the diagram

1 no because text is too small

At level 3, was the diagram easy to read? Why or Why not?

5 qualified yes, can only see part of the diagram.

ER-Diagram:

At level 1, was the diagram easy to read? Why or Why not?

2 qualified yes, readable except for the text in the diagram

3 no because of small text size

At level 2, was the diagram easy to read? Why or Why not?

2 qualified yes, readable but text is still small and can only see part of the diagram

3 no because text is too small or the overlay was in the way.

At level 3, was the diagram easy to read? Why or Why not?

2 qualified yes, can only see part of the diagram

3 no because overlay is in the way and/or can only see part of the diagram at once.

The main follow up questions that were intended to determine if the graphics through the overlay are usable are in Table 6.16 below.

	Organizational Diagram Answers		**ER-Diagram Answers**	
	Yes	**No**	**Yes**	**No**
Was zooming in and out of the diagram helpful for reading the diagram?	5		5	
Were there any parts of the diagram which were confusing or difficult to read because of the overlay?	2	3	3	2
If you were working with a visually impaired person, can you see the diagram well enough through the overlay to help this person?	4	1	3	2

Table 6.16 - Participants answers to questionnaire

6.3 AUDIO ONLY READING PROTOTYPE

This method focuses on whether the system is describing a diagram similar to what the participant is expecting. It is important to note that since the system has been built with the ability to modify the appearance of a diagram, it is not the details of the visual appearance of each diagram type (example: in an organizational diagram should the employees be in circles or should they be in squares) that we are interested. Instead it is the matching of the layout of the objects, what each object is and the object’s attributes and relationships that this testing is most interested in.

This method focuses on whether the contents of a diagram are usable in terms of effectiveness and satisfaction. This method evaluated the system with a variety of diagrams including that of an ER-Diagram. Reading an ER-Diagram requires technical training in database design.

6.3.1 Audio only Reading Prototype Evaluation Design

For this testing, five sighted users with database experience used the method 2 prototype design. Finding visually impaired subjects willing to participate is difficult (Califf, Goodwin and Brownell, 2008; and see also Schneider and Strothotte, 2000) without adding the extra requirement that they must also have database training.

After a quick tutorial on how to use VATagrams to read diagrams, each user was presented two diagrams using VATagrams. In order to reduce the time of each testing session and yet still be able to investigate large diagrams, participants were provided with partially completed paper copies of the diagram. They were asked to manually recreate the remaining pieces of the diagrams VATagrams describes. The participants were free to explore the diagrams on VATagrams at their own speed. Participants were also given a cheat sheet of all the commands as this was not an exercise to test their memories. Each testing session lasted approximately 1.5 – 2 hours.

The diagrams were (Appendix G):

1. ER-Diagram – The diagram had 15 objects. An ER-Diagram has a user-specified layout and was created by the researcher. The partial diagram provided to the participants included 7 objects and their attributes.
2. Organizational diagram – the diagram has a Top Down structure with 40 objects. It includes names, title and department. The partial diagram provided to the participants included 30 objects and their attributes.

Testing the above mentioned diagrams will provide insight into both the successful description of different diagram types as well as diagram complexity (number of objects). To gain this insight, data was collected by looking at:

1. Effectiveness:

Effectiveness was investigated via three questions.

   a. Can the tool be used to read a complex diagram?
   b. Can the tool be used to read different types of diagrams?
   c. Why did the participants make mistakes?

Questions 1 and 2 above were answered by looking at the success rate score. A high score will indicate that yes complex diagrams and different types of diagrams can be supported by the tool. Learning why the participants made mistakes will help improve the system to increase accuracy rates.

By comparing the participant-created manual drawing with the actual visual diagram or answer key, the calculation for success rates can be made. Success rates are determined by a point system and work similar to an exam format (where each correct answer to a question is rewarded with a point). The point system was chosen because the assumption was made that the complexity of the task would make 100% effectiveness difficult to achieve. However, since the system was being tested to determine the extensibility of the system, the point system will show any trends in participant improvement between the two diagrams. The point system is assigned as follows:

- For each object, a point was assigned for the following:
    Correct object's name
    Correct attribute's name(s)
- For each relationship, a point was assigned for the following
    Each correct object in a relationship

Reasons for mistakes were determined by providing participants with a paper copy of the actual visual diagram (answer key) and asking them to complete a questionnaire (refer to Appendix G) comparing the two diagrams.

2. Satisfaction was determined by the following methods:

    a. The questionnaire asks about the participant's satisfaction with determining information from the diagram.

    b. General observations were made and recorded by the researcher manually in a notebook. The researcher looked for issues that may have caused the participant to not score a point.

6.3.2 Audio only Reading Prototype Results

Five participants 2 female, 3 male all between the ages of 25-34 participated in the study. All had some experience with a touch screen product. The following is the list of results.

6.3.2.1 Effectiveness

6.3.2.1.1 Accuracy achieved by participants

The researcher marked both diagrams. Participants achieved a high level of accuracy. For the ER-Diagram the average score was 38/42 (90%) with the highest score being 42/42 (100%) and the lowest score being 35/42 (83%). For the Organizational diagram the average score was 36/40 (90%) with the highest being 37/40 (93%) and the lowest being 31/40 (78%). See Table 6.17 below for the complete listing of percentages for each participant per diagram.

Participant	**ER –Diagram**	**Organizational Diagram**
1	83%	93%
2	93%	93%
3	95%	78%
4	86%	90%
5	100%	93%

Table 6.17 - Percent accuracy achieved by participants for each type of diagram.

6.3.2.1.2 Participants' surprise to differences

After the participants completed their diagrams, they were asked to compare their diagram to an answer key. They were then asked a series of questions to help determine what some causes for the differences might be. See Table 6.18 below for the list of questions and the participants' answers.

	Organizational Diagram		**ER-Diagram**	
Questions:	**Yes**	**No**	**Yes**	**No**
When you compared your drawing to the actual diagram were there any differences you were surprised about?	1	4	1	4

When you compared your drawing to the actual diagram were there any differences you were Not surprised about?	2	3	2	3

Table 6.18 – Participants’ answers to questions to determine reasons for mistakes.

Participants explained that mistakes were mainly due to misunderstanding the screen reader so items such as names and attributes were spelt wrong.

6.3.2.2 Satisfaction

6.3.2.2.1 Participants’ Evaluation of the Ease of Determining Information from Each Diagram

Participants were asked for each diagram to rate on a scale of 1-5, where 1 is extremely difficult and 5 is extremely easy, the ease with which they could:

1. determine objects,
2. determine attributes,
3. determine relationships, and
4. draw the diagram from information provided by the prototype.

Table 6.19 displays the average ratings given by the participants (where 5 is extremely easy).

	Determine Objects	**Determine attributes**	**Determine Relationships**	**Draw the Diagram**
ER-Diagram	3.2	3.6	3.6	3.2
Organizational Diagram	3.8	4	4.2	4.2

Table 6.19 - Average ratings per diagram for each task. Ratings scale is 1-5 where 1 is very difficult and 5 is very easy.

6.3.2.2.2 Researcher's observations

During the sessions, 2 participants asked if there was a pause function so that they could pause the voice output as they worked.

One participant mentioned that he would like a method to take a location and relocate there (as opposed to an object). He thought this could be useful in the case where you would use the Search function to return the locations and then go to some of those locations.

While the participants worked, they all wrote down locations so that they could remember them.

CHAPTER 7

7 CONCLUSION

VATagrams is a series of prototypes created for the iPad. These prototypes can be used as the building blocks to create a complete useable system. The interface allowed users to input information via touching gestures and voice. The research determined that a combination of these input methods makes it possible for visually impaired persons to use the system. The resulting visual diagrams make it possible for the visually impaired to share diagrams with sighted individuals.

7.1 DISCUSSION

The prototypes were evaluated in terms of usability using effectiveness, efficiency and satisfaction as measures. Suggestions and observations were also obtained.

7.1.1 Effectiveness

Effectiveness looked was looked at in the general usability evaluation and in the audio only reading evaluation.

7.1.1.1 Visually impaired, blindfolded and sighted participants

The general usability study had a low rate of incompletes. There were only four cases where the participant failed to complete the task or provided an incorrect answer. One of these tasks involved answering the question “Who does Sam supervise”. The answer was no one; however, the problems that the participants had with this task as discussed in section 6.1.2.3.2 indicates that the system must also indicate the case when there are no relationships for a given object.

As part of the general usability study, the error rates decreased for each subsequent task that required the use of the same command set. For example, there were 3 tasks that all involved finding the department name and title of an object. This trend is most noticeable when looking at the average error rate for the visually impaired participants. For the first task of finding an object's department name and title, they had an error rate of 8, the second task had an error rate of 3.6 and the third task had a rate of 2.2. This shows that with extended use, the error rate can drop.

The visually impaired participants commented that the more they worked with the system, the greater their understanding. The researcher observed improvements in effectiveness as the participants gained experience with the prototype. It is possible that this learning curve attributed to their higher error rate. Participants were asked to determine a person's title and department three times. The average error rates decreased after each time indicating that performance improved with use of the system.

The system used a very small voice recognition dictionary and in order to have a complete program a very large dictionary would be needed. Refer to section 7.3.1 which discusses improvements needed in more detail.

7.1.1.2 Sighted participants

The participants from the final evaluation noted that most of the differences in their diagrams compared to the answer key were due to spelling errors and mishearing the screen reader. This could be improved by allowing some or all of the following abilities:

1. change the speed of the screen reader,
2. have the screen reader spell out words,
3. pause the reading voice, and
4. change the voice of the screen reader.

7.1.2 Efficiency

In the general usability study, the ratio of commands used by the participant in comparison to the most optimal number of commands, decreased as participants completed similar tasks. This trend is most noticeable when looking at the blindfolded participants and finding the title/department of an object. With the first object their ratio was 4.9:1, the second object it was 1.6:1 and the third object it was 1.3:1. These results were also affected by 1-2 participants. For example, using the blindfolded participants, one participant had a ratio of 14:1 whereas the remaining participants all had ratios below or equal to 3.5:1. It is expected that efficiency would improve with improved training and increased experience.

On average, creating objects was most efficiently done by all participants (Refer to Figure 6.4). This command left the least amount of options open to the participants and participants commented that the liked adding the objects.

There was an average of 4 commands out of 12 that were used by more than half of the sighted users. These participants used the navigation commands (zoom, find, relocate) but not the reading commands. This shows that the sighted participants preferred to visually read the diagrams over obtaining aural information.

The number of times that the commands were reviewed by participants was almost equal when comparing Blindfolded to Blind participants. These participants relied completely on receiving information aurally so they need to use more commands, whereas the sighted participants mainly used only the zoom and relocate commands so had less commands they needed to remember. As suggested by one visually impaired participant, a help system may assist the user.

Participants did not use the commands that listed the location information as much as the other commands. For example: ‘read an object and its location’ was only used by 2 out of 15 participants and ‘read an object, its relations and location’ was only used by 5 out of 15 participants. This indicates that having three separate commands to deal with locations is not needed. Instead it might be better to offer a method to turn location information on or off for the few times it might be used. This would be better than trying to remember three commands.

7.1.3 Satisfaction

7.1.3.1 Visually Impaired, Blindfolded and Sighted Participants

All visually impaired, blindfolded and sighted participants ranked the commands as difficult to remember; 2.6, 2.4 and 2.8 out of 5 (where 1 represents extremely difficult and 5 represents extremely easy) prospectively. However, all of the blind participants commented that they thought that with extended use of the system they would be able to easily remember the commands. Three of the sighted participants commented that there where too many commands. This may be improved by removing the location information as discussed in section 7.1.2.

When asked if participants would use the program from the general usability study, 69% of all participants who responded said they would use the program and 100% of the visually impaired participants said they would use the program. Visually impaired participants also gave an average rating of the tools as 8.8 out of 10 or very good.

As mentioned in section 6.1.2.1.3, when trying to complete tasks, the sighted participants focused on the visual aspects of the diagram and did not make use of any auditory output. The sighted participants' average rating for the tools from the general usability study was a 6.6 out of 10. Perhaps a larger focus on the graphics may improve their ratings.

7.1.3.2 Sighted participants

Sighted participants seemed to agree that for the most part, while zoom levels 1 and 2 did allow one to see an overview of the diagram, the images were too small to read the labels clearly. They also seemed to be concerned with only being able to see a portion of the diagram when zoomed into level 3. That said, one of the participants commented that the grid helped one to focus solely on a portion of the diagram and if they were working with a blind person, that the grid would make it easier to determine that they were indeed viewing the same objects.

A few of the sighted participants commented that the overlay sometimes blocked important information. While originally the images were designed such that they appeared only between the grid lines, shifting of the overlay was not taken into account. However, all 5 participants mentioned that they would be able to see well enough to help a visually impaired person with some amount of detail and information.

One of the participants noted that the changing of the diagrams was a little disorientating. He/she thought that perhaps some effect could be used so that a visual person could see the zooming happen instead of one image just being replaced with another.

The results seem to indicate that future work would need to be done in order to make the diagram more readable. This could be as simple as using, as one participant suggested, a transparent overlay. The solution might be somewhat more complicated and allow users to pan the images at higher zoom levels.

The participants rated the Organizational diagram as being easier than the ER-Diagram to read. There are two possible reasons for this.

1. Working with the ER-Diagram was harder because it was the first diagram presented. By the time they had started work on the Organizational Diagram they already had gained a good sense of how to use the prototype.
2. Or, the number of relationships in an ER-Diagram is greater and so the system returns more information at once. As indicated by one participant, the amount of this information could be too much at once. In fact, three participants asked if there was a way to pause or stop the speaking during the sessions.

Perhaps the lowest score on the Organizational Diagram was due to the participant forgetting to display the department names for each of the objects.

7.1.4 Suggestions and Observations

The most encouraging aspect of this study was the fact that the visually impaired participants were so excited after using the prototypes. This was also supported by these participants indicating they would use the system and they actively provided comments and feedback.

From an observer's point of view, the sighted participants from the evaluation of the Audio Only Prototype seemed somewhat in doubt that they could complete a diagram simply by using the provided prototype. However, all seemed pleased when they were able to complete the diagrams. One participant even mentioned that the tool made it easy to complete the diagrams.

This shows that the concepts used to display verbal diagrams were successful in both allowing people to navigate them and to understand the verbal representations of the diagrams.

7.2 CONTRIBUTIONS

The creation of this prototype and thesis makes the following contributions:

1. Provide a list of guidance items for presenting diagrams to the visually impaired.
2. Evaluation of a prototype for a tool for creating relationship based diagrams without the use of sight.
3. Provide an understandable verbal representation of relationship based diagrams.
4. Display verbal diagrams which can be navigated tacitly.
5. Provide a design of a tactile overlay for an iPad which allows one to navigate diagrams.

7.3 FUTURE WORK

The potential for this project is large. Not only has this prototype provided a strong foundation for developing a highly usable program for the visually impaired, but it also uncovered areas for improvement. Along with these areas, there are other features and research which could be pursued in the future. These features and research areas include:

1. Importing and exporting diagrams to and from other systems
2. Connecting to a webserver
3. Working with charts and graphs
4. Compatibility with iPhone and iPod
5. Ability to support larger diagrams
6. Using a keyboard for input
7. Enhanced graphical abilities for sighted users

7.3.1 Improving the current design

Voice recognition is an important aspect of a successful system. A more commercial product with stronger speech recognition would need to be found because OpenEars has weak voice recognition and a non-scalable text-to-speech engine. OpenEars is not strong enough as shown by the number of voice recognition errors. The small voice library is also a large drawback as all of the voices were very mechanical which makes them difficult to understand. Currently the best products house their language recognition software on webservers and answer queries sent by clients over the internet. This could potentially add to extra research in how to handle wait time as it is possible that there could be long wait periods based on the server load and internet speed.

Another item that can be improved is the number of commands. Too many times participants commented that there were too many commands. Not only that, it seems that a large number of the commands were not really used. For example, participants did not really use the location values presented in the information. Perhaps instead of having a command for each information set, which returns the location (3 commands), a second Read Mode should be added to the system. This read mode would include the location information. Also there were comments made that the Relocate and Find/Search commands were not all that different, and that they see more value in being able to go to the locations. Perhaps the functions of these two commands could be combined such that the user would have to decide which item to relocate to in the case when multiple items are returned.

One participant mentioned that it was slightly disorientating the way the diagram images changed when the zoom level changed. Sighted participants also mentioned that it was difficult to read the diagrams at the lower zoom levels. It would be valuable to investigate the participant's suggestion and look into how to animate the process in such a way that it would provide the sighted user with more visual information. This visual animation should somehow display how the objects are being zoomed into.

Across different evaluations, sighted participants mentioned that the graphics were not always easy to read and were sometimes blocked by the overlay. Two participants also mentioned they felt as though the overlay moved which affected the touches the iPad picked up. A more dense material should be used for the overlay such as a hard clear plastic. This would help eliminate both problems. An alternative would be to allow sighted participants the ability to remove the overlay. To do this, visual information would need to be provided to the user so that he or she can see the areas which were previously defined by the overlay.

One of the blind participants mentioned that there should be some method for calibrating the overlay with the system so that a visually impaired person could place the overlay on himself or herself to ensure the visual diagrams beneath would be lined up correctly.

7.3.2 Importing and exporting diagrams from other systems

The system only supports the creation and saving of information within itself. A good feature would to be able to export and import diagrams in other file formats. For example, it would be quite substantial to support SVG diagrams. In this case one could be sharing diagrams between the IVEO system. Since the data is already stored in database format, the ability to create the queries and code to export this data in different formats is possible.

7.3.3 Connecting to a Webserver

Presently, the system is stand alone. Designing an infrastructure or even a part of the infrastructure that could reside on a webserver could allow potential benefits.

As previously mentioned the current voice recognition capabilities are limited because of the libraries available for the iPad. It is however possible to connect to a webserver, which could handle the voice recognition.

Another benefit to using a webserver is that one could potentially share diagrams and diagram definitions more easily.

7.3.4 Working with charts and graphs

Charts and graphs are not relationship based and so are not currently supported by the system. Further research would need to be done to determine the best way to represent these types of diagrams on a touchpad interface. It is likely that a different screen overlay and navigation method would be required.

7.3.5 Compatibility with the iPhone and iPod

Taking into account the much smaller screen size, VATagrams is not truly compatible with Apple's smaller touch devices. Research would need to be done to determine if one could modify VATagrams to run on the smaller devices. The small screen size limits the amount of gestures one can perform. This means that simply resizing the overlay to be smaller would not work. Research would need to be done to determine the effects of changing the overlay to have fewer grids would be effective.

It is also possible that with a more powerful speech recognition engine, the interface could be controlled completely by voice. In this case it would be interesting to compare the differences in speed, accuracy and comprehension (understanding what is going on without being able to physically see the results).

7.3.6 Ability to support larger diagrams

As mentioned in section 4.3, the current system supports up to 729 objects. In the cases of tiered diagrams (ie: family tree) the system supports even less. There are of course other options that could be explored in order to expand this system.

The system supports fewer objects because many of the grids remain unused. For example, in the case of a family tree, at the topmost level there may only be one father and one mother. This means that 25 grids remain unused. Research could be done on how these grids could be used and yet not confuse the user.

Another option is to have sub-diagrams. In this scenario, a large diagram is made up of many sub-diagrams. Research would need to be done to determine the best way to interact between the sub-diagrams.

7.3.7 Ability to use keyboard for input

iPads can connect to some Bluetooth keyboards and even have keyboard docks. Although not implemented currently, it is quite conceivable that VATagrams could be modified to allow keyboard input.

7.3.8 Enhanced graphical abilities for sighted users

As mentioned by multiple sighted users in various evaluations, it is not easy to see all the information about a diagram at once at a readable size. Further research could be done to evaluate how panning from side to side might work to alleviate this problem.

Another item could potentially be the addition of a more scalable grid. This means when it is a smaller diagram, instead of objects being assigned to a 27x27 grid, the grid could collapse to be smaller.

Currently the tool only allows for landscape orientation. It is possible that some users would prefer to work in portrait mode. A technique for performing this would need to be done as to how to inform the participants of the changes.

7.4 CONCLUSION

To allow the visually impaired the ability to share the same advantages in school and work as sighted colleagues, an accessible diagramming tool is needed. A series of prototypes for a suitable tool for the visually impaired for creating and reading diagrams was created to run on an iPad. These prototypes allowed individuals to create and read relationships and components of the relationships. A graphical representation of these diagrams was also created which can be used by a sighted person if needed.

These prototypes were tested for usability using measures of efficiency, effectiveness and satisfaction. The prototypes were tested with legally blind, blindfolded and sighted participants. The results of the evaluation indicate that the prototypes contain the main building blocks that can be used to complete a fully functioning application to be used on an iPad. This resulting application could be successfully used by the visually impaired to create, read and share diagrams.

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APPENDIX A

DATABASE SCHEMA

Diagram Type Definitions

a) Diagram Type
    a. ID
    b. Name
    c. Description
    d. Layout type
b) Object type
    a. ID
    b. DiagramID
    c. Object name
    d. Drawing instuctions
c) Attributes type
    a. ID
    b. Object id
    c. Name
    d. Text location
d) Relationship types
    a. Id
    b. Name
    c. Draw instructions

Diagrams:

a) Diagram
    a. ID
    b. Name
    c. Typeid
    d. Description
b) Objects
    a. Id
    b. Objecttypeid
    c. Diagramid
    d. area1loc
    e. area2loc

    f. area3loc

c) Relationships
    a. Id
    b. Diagramid
    c. Object1ID
    d. Object2ID
    e. Name

d) RelationshipAttributes
    a. Id
    b. Relationshipid
    c. Name/text

e) ObjectAttributes
    a. Id
    b. Objectid
    c. Name/text

APPENDIX B

DICTONARIES

Reading Prototype Dictionary

Word	Phonetic Pronunciation
FINANCE	F AH N AE N S
FINANCE(2)	F IH N AE N S
FINANCE(3)	F AY N AE N S
GO	G OW
HOME	HH OW M
JILL	JH IH L
LILY	L IH L IY
NO	N OW
SAM	S AE M
SUSAN	S UW Z AH N
TED	T EH D
YES	Y EH S

Creating and Editing Prototype Dictionary

Word	Phonetic Pronunciation
ADMINISTRATIVE	AH D M IH N AH S T R EY T IH V
ADMINISTRATOR	AH D M IH N AH S T R EY T ER
ANNA	AE N AH
ASSISTANT	AH S IH S T AH N T
BARRY	B AE R IY
BARRY(2)	B EH R IY
BOOK	B UH K
C.E.O	S IY IY OW
COMPANY	K AH M P AH N IY
DEPARTMENT	D IH P AA R T M AH N T
DOUG	D AH G
GO	G OW
HOME	HH OW M

INFORMATION	IH N F ER M EY SH AH N
INFORMATION(2)	IH N F AO R M EY SH AH N
JACK	JH AE K
JILL	JH IH L
JOHNNY	JH AA N IY
KATE	K EY T
KEEPER	K IY P ER
LORI	L AO R IY
MANAGER	M AE N AH JH ER
MANAGER(2)	M AE N IH JH ER
NAME	N EY M
NETWORK	N EH T W ER K
NO	N OW
PERSON	P ER S AH N
PROGRAMMER	P R OW G R AE M ER
SALES	S EY L Z
SARA	S EH R AH
SUPERVISOR	S UW P ER V AY Z ER
TECHNOLOGY	T EH K N AA L AH JH IY
TITLE	T AY T AH L
TODD	T AA D
V.P.	V IY P IY
X.	EH K S
X.(2)	AE K S
X.Y.Z.	EH K S W AY Z IY
Y.	W AY
YES	Y EH S

Visual Representation Method 2 Dictionary (ER-Diagram)

Word	Phonetic Pronunciation
ADDRESS	AE D R EH S
ADDRESS(2)	AH D R EH S
ALLERGY	AE L ER JH IY
BEDS	B EH D Z
CABIN	K AE B AH N
CAMPER	K AE M P ER
CITY	S IH T IY
CLASS	K L AE S

COUNCELLOR	K OW AH N S EH L ER
DESCRIPTION	D IH S K R IH P SH AH N
DOSAGE	D OW S AH JH
DOSAGE(2)	D OW S IH JH
DOSE	D OW S
DRUG	D R AH G
DRUGS	D R AH G Z
EFFECTS	IH F EH K T S
EFFECTS(2)	IH F EH K S
EFFECTS(3)	IY F EH K T S
EFFECTS(4)	IY F EH K S
EMPLOYEE	EH M P L OY IY
EMPLOYEE(2)	IH M P L OY IY
GO	G OW
HOME	HH OW M
I.D.	AY D IY
LOCATION	L OW K EY SH AH N
NAME	N EY M
NO	N OW
NUMBER	N AH M B ER
PARENT	P EH R AH N T
PERSON	P ER S AH N
PHONE	F OW N
POSITION	P AH Z IH SH AH N
POSITIONS	P AH Z IH SH AH N Z
REACTION	R IY AE K SH AH N
REGULARMED	R IH G Y UW L AH R M D
S.I.N.	EH S AY EH N
SIDE	S AY D
STOCK	S T AA K
TIME	T AY M
WORK	W ER K
YES	Y EH S

Visual Representation Method 2 Dictionary (Organizational Diagram)

Word	**Phonetic Pronunciation**
ACCOUNTANT	AH K AW N T AH N T
AND	AH N D

AND(2)	AE N D
ANNA	AE N AH
ARTIST	AA R T AH S T
ARTIST(2)	AA R T IH S T
ASSISTANT	AH S IH S T AH N T
AUDITOR	AO D IH T ER
BARNEY	B AA R N IY
BILL	B IH L
BRITTNEY	B R IH T N IY
C.E.O.	S IY IY OW
CARRIE	K EH R IY
CHAD	CH AE D
CLERK	K L ER K
CONTROLLER	K AH N T R OW L ER
DARLENE	D AA R L IY N
DESIGN	D IH Z AY N
DESIGNER	D IH Z AY N ER
DEVELOPMENT	D IH V EH L AH P M AH N T
DOUG	D AH G
EXECUTIVE	IH G Z EH K Y AH T IH V
FINANCE	F AH N AE N S
FINANCE(2)	F IH N AE N S
FINANCE(3)	F AY N AE N S
GO	G OW
GREG	G R EH G
H.R.	EY CH AA R
HEALTH	HH EH L TH
HOME	HH OW M
HUMAN	HH Y UW M AH N
HUMAN(2)	Y UW M AH N
I.T.	AY T IY
JACK	JH AE K
JASON	JH EY S AH N
JESSIE	JH EH S IY
JILL	JH IH L
JIM	JH IH M
JOE	JH OW
JULIE	JH UW L IY
KAREN	K EH R AH N

KELLY	K EH L IY
KIM	K IH M
LILLY	L IH L IY
LINDSEY	L IH N D Z IY
MAGAN	M EY G AH N
MANAGER	M AE N AH JH ER
MANAGER(2)	M AE N IH JH ER
MANANGER	M AE N AE NG G ER
MARY	M EH R IY
MATT	M AE T
MIKE	M AY K
NANCY	N AE N S IY
NO	N OW
OFFICER	AO F AH S ER
OFFICER(2)	AO F IH S ER
ORGANIZATIONAL	AO R G AH N AH Z EY SH AH N AH L
PAM	P AE M
PAYROLL	P EY R OW L
PROGRAMMER	P R OW G R AE M ER
PROJECT	P R AA JH EH K T
PROJECT(2)	P R AH JH EH K T
RACHEL	R EY CH AH L
REP	R EH P
REP(2)	R EH P R IY Z EH T AH T IH V
RESOURCES	R IY S AO R S IH Z
ROBIN	R AA B AH N
ROBIN(2)	R AA B IH N
ROSS	R AA S
ROSS(2)	R AO S
SAFETY	S EY F T IY
SALES	S EY L Z
SAM	S AE M
SENIOR	S IY N Y ER
SHAWN	SH AO N
STAN	S T AE N
SUSAN	S UW Z AH N
TECH	T EH K
TED	T EH D
TERRY	T EH R IY

TIM	T IH M
V.P.	V IY P IY
VICTOR	V IH K T ER
YES	Y EH S

APPENDIX C

OVERLAY POST-TESTING QUESTIONNAIRE

1. Gender: M/F
2. Have you had any experience with an iPod Touch, iPhone or iPad?
3. Have you had any experience using other touch screens?
4. On a scale of 1 – 5 where 1 is extremely difficult , 2 is somewhat difficult, 3 is neither difficult nor easy, 4 is somewhat easy and 5 is extremely easy, How would you rate the following?
    a. How easy was it to press the mode button?
    Extremely Difficult Extremely Easy
    1 2 3 4 5

    b. How easy was it to press the talk button?
    Extremely Difficult Extremely Easy
    1 2 3 4 5

    c. How easy was it to press the scroll buttons?
    Extremely Difficult Extremely Easy
    1 2 3 4 5

    d. How easy was it to pinch in on a grid?
    Extremely Difficult Extremely Easy
    1 2 3 4 5

    e. How easy was it to pinch out on a grid?
    Extremely Difficult Extremely Easy
    1 2 3 4 5

f. How easy was it to horizontally swipe a grid with one finger?
Extremely Difficult Extremely Easy
1 2 3 4 5

g. How easy was it to horizontally swipe a grid with two fingers?
Extremely Difficult Extremely Easy
1 2 3 4 5

h. How easy was it to horizontally swipe a grid with three fingers?
Extremely Difficult Extremely Easy
1 2 3 4 5

i. How easy was it to single tap a grid?
Extremely Difficult Extremely Easy
1 2 3 4 5

j. How easy was it to double tap a grid?
Extremely Difficult Extremely Easy
1 2 3 4 5

k. How easy was it to triple tap a grid?
Extremely Difficult Extremely Easy
1 2 3 4 5

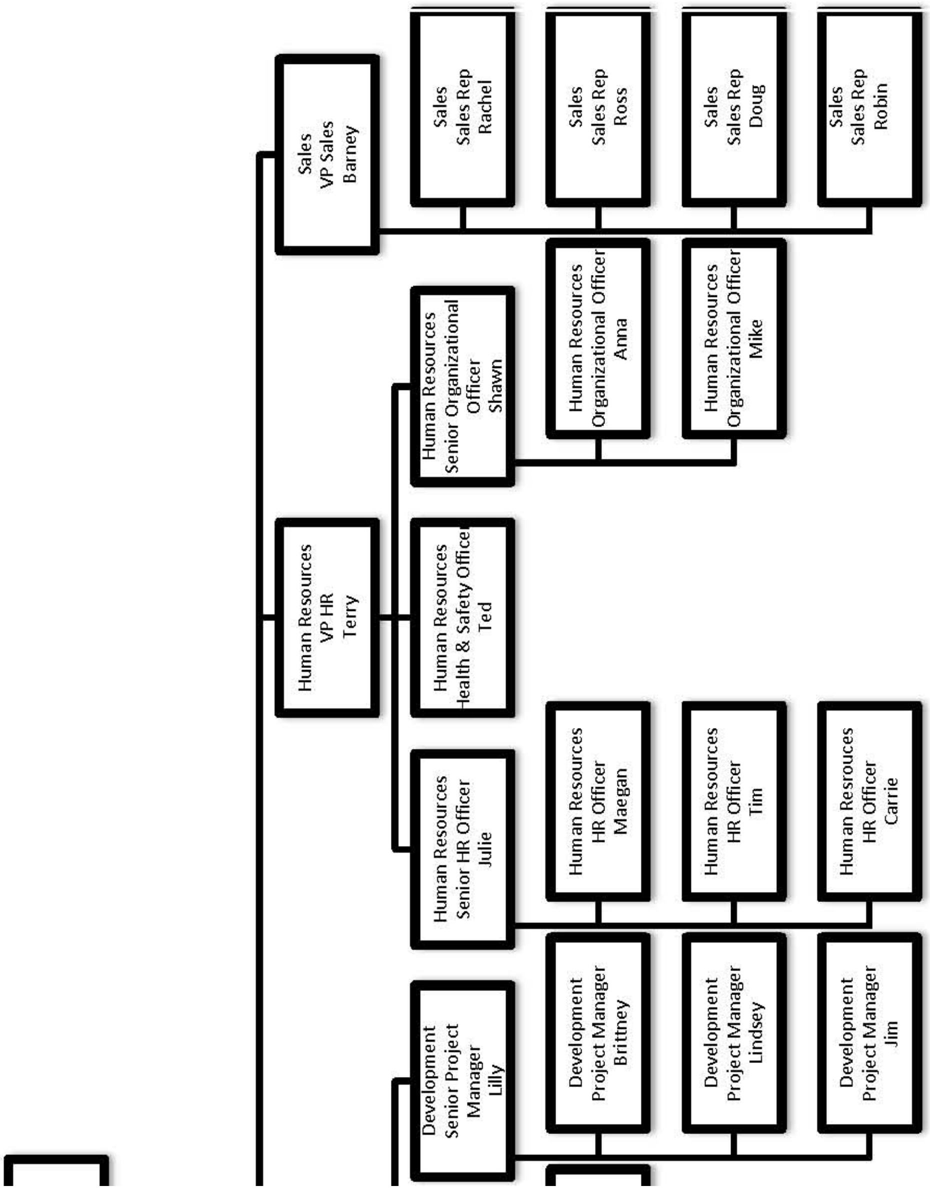
l. How easy was it to use different gestures in combination with buttons?
Extremely Difficult Extremely Easy
1 2 3 4 5

m. Overall, how easy was it to use the techniques?
Extremely Difficult Extremely Easy
1 2 3 4 5

5. Do you have any comments or suggestions?

APPENDIX D

AUDIO AND GRAPHICAL READING PROTOTYPE



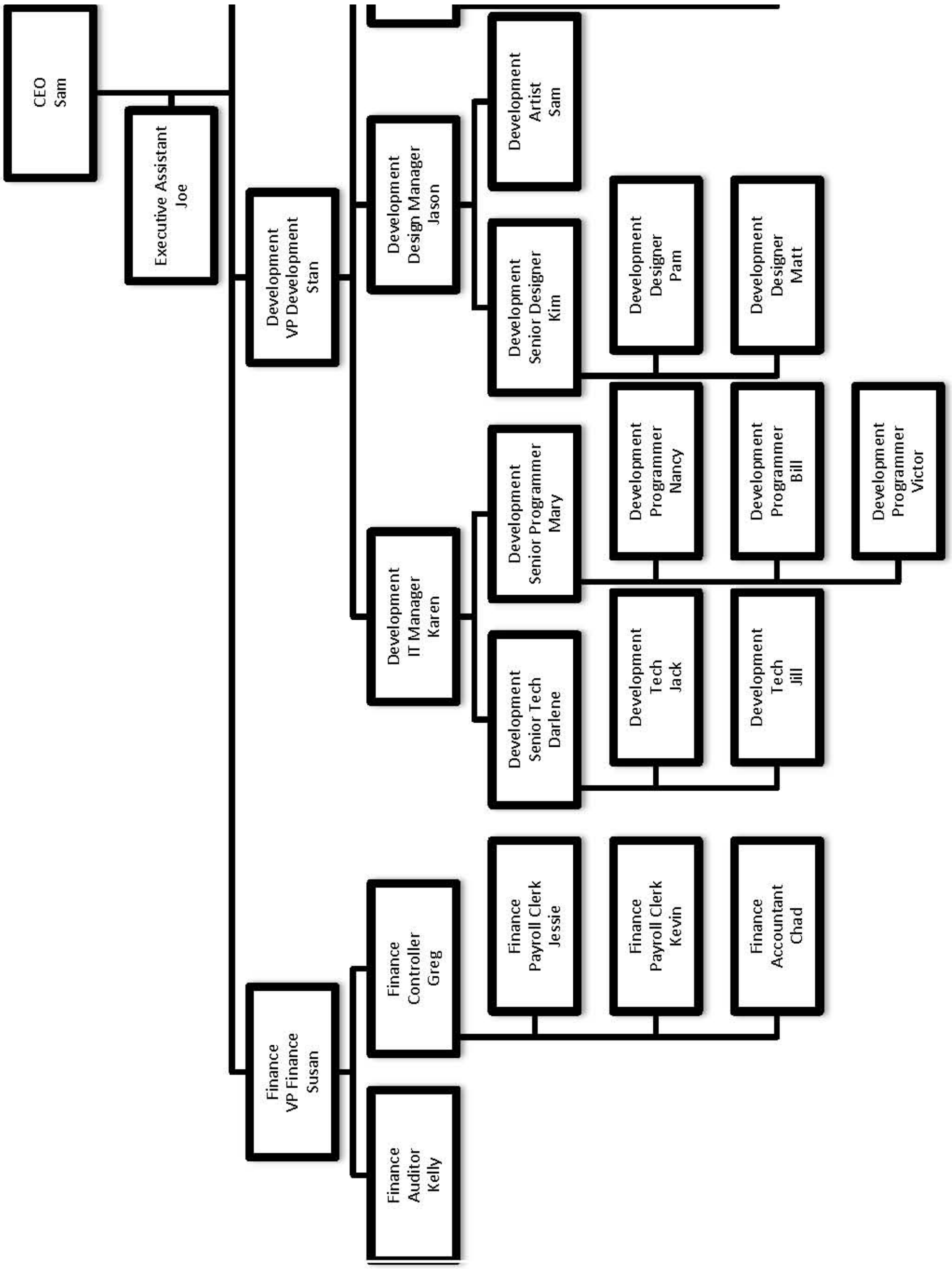


Figure D.1 - Organizational Diagram for Reading Prototype

APPENDIX E

SENARIO FOR CREATING ORGANIZATIONAL DIAGRAM

In the XYZ Company, there are 10 employees. The CEO's name is Kate. She supervises Jack and Jill. Jack is the VP X and supervises Department X. He supervises Johnny and Lori.Johnny is the administrative assistant and Lori is the book keeper.Jill is the VP Y and supervises Department Y. She supervises Todd who is the Information Technology manager and Sara who is the Sales Manager.Todd supervises Doug and Anna. Doug is the Network Administrator and Anna is the Programmer.Sara supervises Barry who is the sales person.

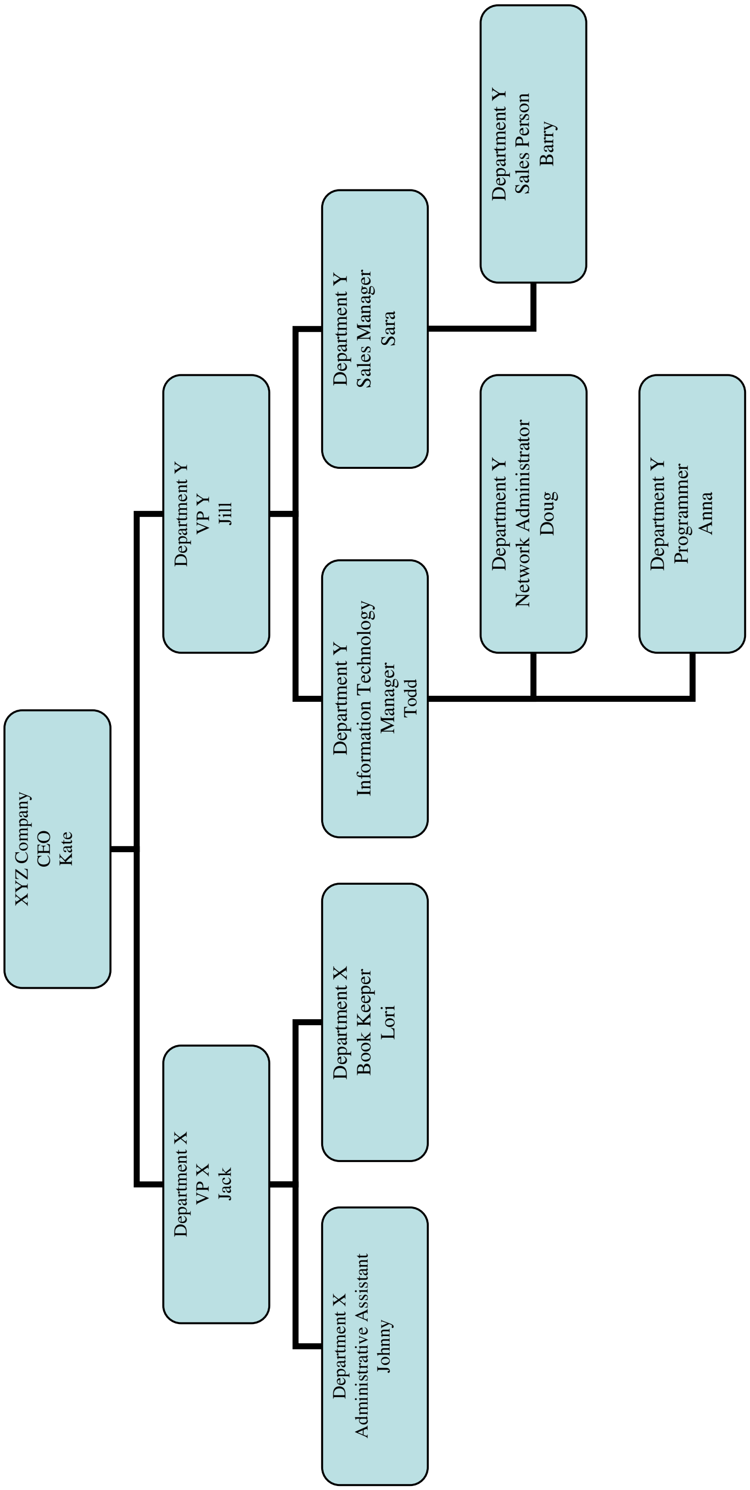


Figure E.1 - Example of what the resulting diagram might look like

APPENDIX F

AUDIO AND GRAPHICAL READING/CREATING AND EDITING POST-TESTING QUESTIONNAIRE

1. Gender: M/F
2. What age group are you in?

    18-24

    25-34

    35-44

    45-54

    55-64

    65-74

    75 or older

3. Please describe your sight abilities. (ie: I have normal vision with the use of contact lenses or glasses.)

1. If you have a visual impairment which cannot be fully corrected with glasses or contact lenses, at what age did your visual impairment become non-correctable?
    a. Birth - 1
    b. 2-4
    c. 5-9
    d. 10-14
    e. 15-19
    f. 20-29
    g. 30-39
    h. 40-49
    i. 50 or older

2. What is your experience with diagrams (select all that apply)?
    - I have experience with visual diagrams
    - I have experience with tactile diagrams
    - I have experience with people reading diagrams to me
3. Have you had any experience with an iPod Touch, iPhone or iPad?
4. Have you had any experience using other touch screens?
5. Where there any features or functionalities in VATagrams that you liked? If yes, what?
6. Where there any features or functionalities in VATagrams that you did not like? If yes, what?
7. Assuming that you needed to use a diagram in the future and you own an iPad, would you use VATagram? Why or why not?
8. On a scale of 1 – 5 where 1 is extremely difficult , 2 is somewhat difficult, 3 is neither difficult nor easy, 4 is somewhat easy and 5 is extremely easy, How would you rate the following?
    - How easy was it to remember all the commands?
      Extremely Difficult Extremely Easy
      1 2 3 4 5

    - How easy was it to read an overview of a diagram?
      Extremely Difficult Extremely Easy
      1 2 3 4 5

    - How easy was it to read specific information about a diagram?
      Extremely Difficult Extremely Easy
      1 2 3 4 5

    - How easy was it to edit a diagram?
      Extremely Difficult Extremely Easy
      1 2 3 4 5

    - How easy was it to create a new diagram?
      Extremely Difficult Extremely Easy
      1 2 3 4 5

- How easy was it to open an existing diagram?
  Extremely Difficult Extremely Easy
  1 2 3 4 5

- How easy was it to move objects within the diagram?
  Extremely Difficult Extremely Easy
  1 2 3 4 5

- How easy was it to move around in a diagram (Zooming in and out)
  Extremely Difficult Extremely Easy
  1 2 3 4 5

- How easy was it to understand the diagram?
  Extremely Difficult Extremely Easy
  1 2 3 4 5

9. On a scale of 1 – 10 where 1 is extremely negative and 10 is extremely positive, how would you rate your overall experience with VATagram?
   Extremely Negative Extremely Positive
   1 2 3 4 5 6 7 8 9 10
10. Where there any features which you would have liked to have which were not already in the program?
11. Do you have any comments or suggestions about VATagrams?

APPENDIX F

GRAPHICAL REPRESENTATION PROTOTYPE

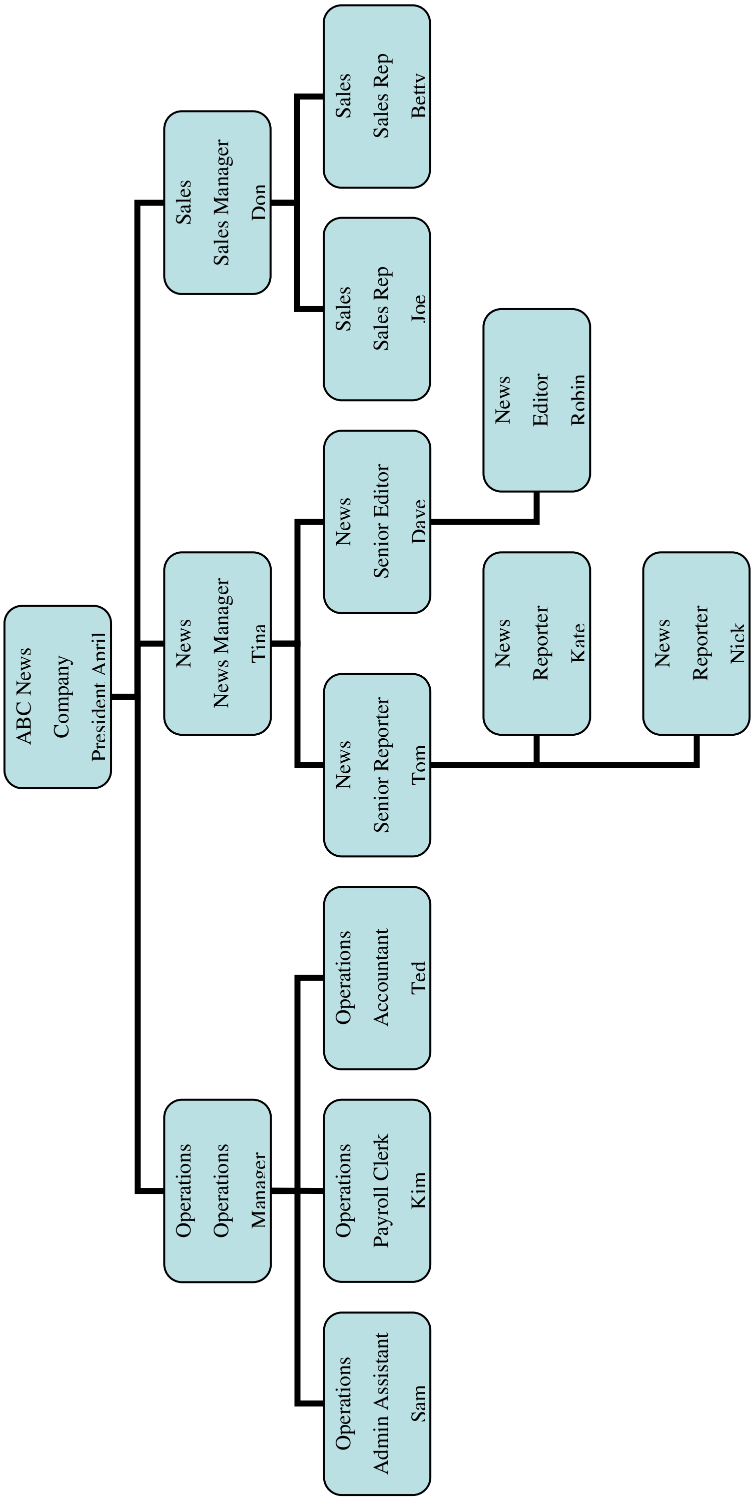


Figure F.1 - Organizational Diagram to be displayed under the Overlay at 3 different zoom levels

UML Based ER-Diagram

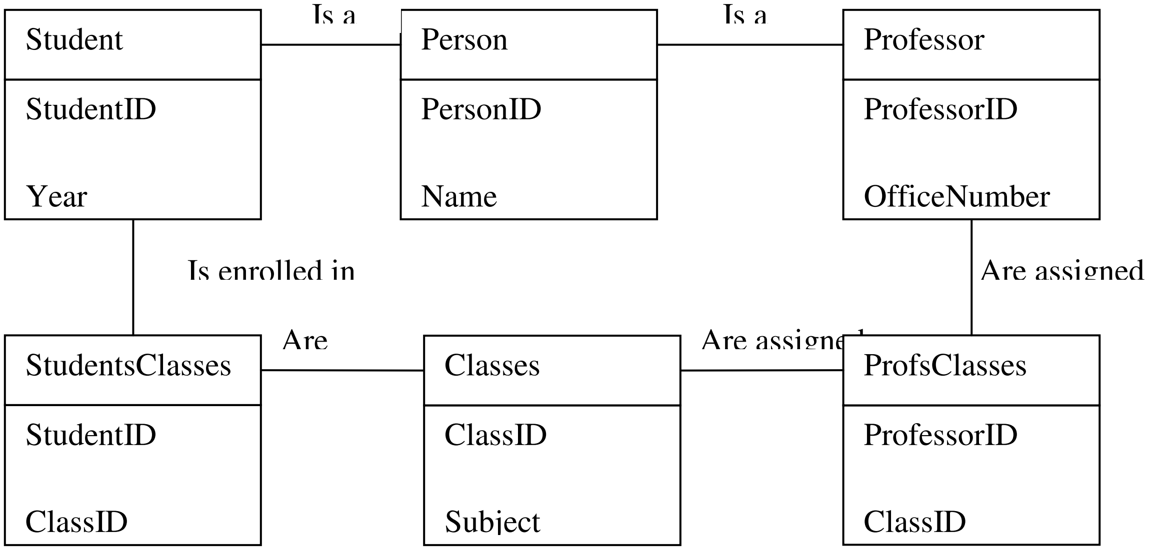


Figure F.2 - ER-Diagram to be displayed under the Overlay at 3 different zoom levels

Graphical Representation Questionnaire

2. Gender: M/F
3. What age group are you in?
    j. 18-24
    k. 25-34
    l. 35-44
    m. 45-54
    n. 55-64
    o. 65-74
    p. 75 or older

Answer the following questions in regards to the Organizational Diagram

4. At level 1, was the diagram was easy to read? Why or why not?

5. At level 2, was the diagram was easy to read? Why or why not?

6. At level 3, was the diagram was easy to read? Why or why not?

7. Was zooming in and out of the diagram helpful for reading the diagram? Why or Why not?

8. Were there any parts of the diagram which were confusing or difficult to read because of the overlay? If yes, please explain.

9. If you were working with a visually impaired person, can you see the diagram well enough through the overlay to help this person? Please explain in detail.

Answer the following questions in regards to the ER-Diagram

10. At level 1, was the diagram was easy to read? Why or why not?

11. At level 2, was the diagram was easy to read? Why or why not?

12. At level 3, was the diagram was easy to read? Why or why not?

13. Was zooming in and out of the diagram helpful for reading the diagram? Why or Why not?

14. Were there any parts of the diagram which were confusing or difficult to read because of the overlay? If yes, please explain.

15. If you were working with a visually impaired person, can you see the diagram well enough through the overlay to help this person? Please explain in detail.

Do you have any other comments or suggestions?

APPENDIX G

AUDIO ONLY READING PROTOTYPE

ER-Diagram provided to participants in paper form to complete

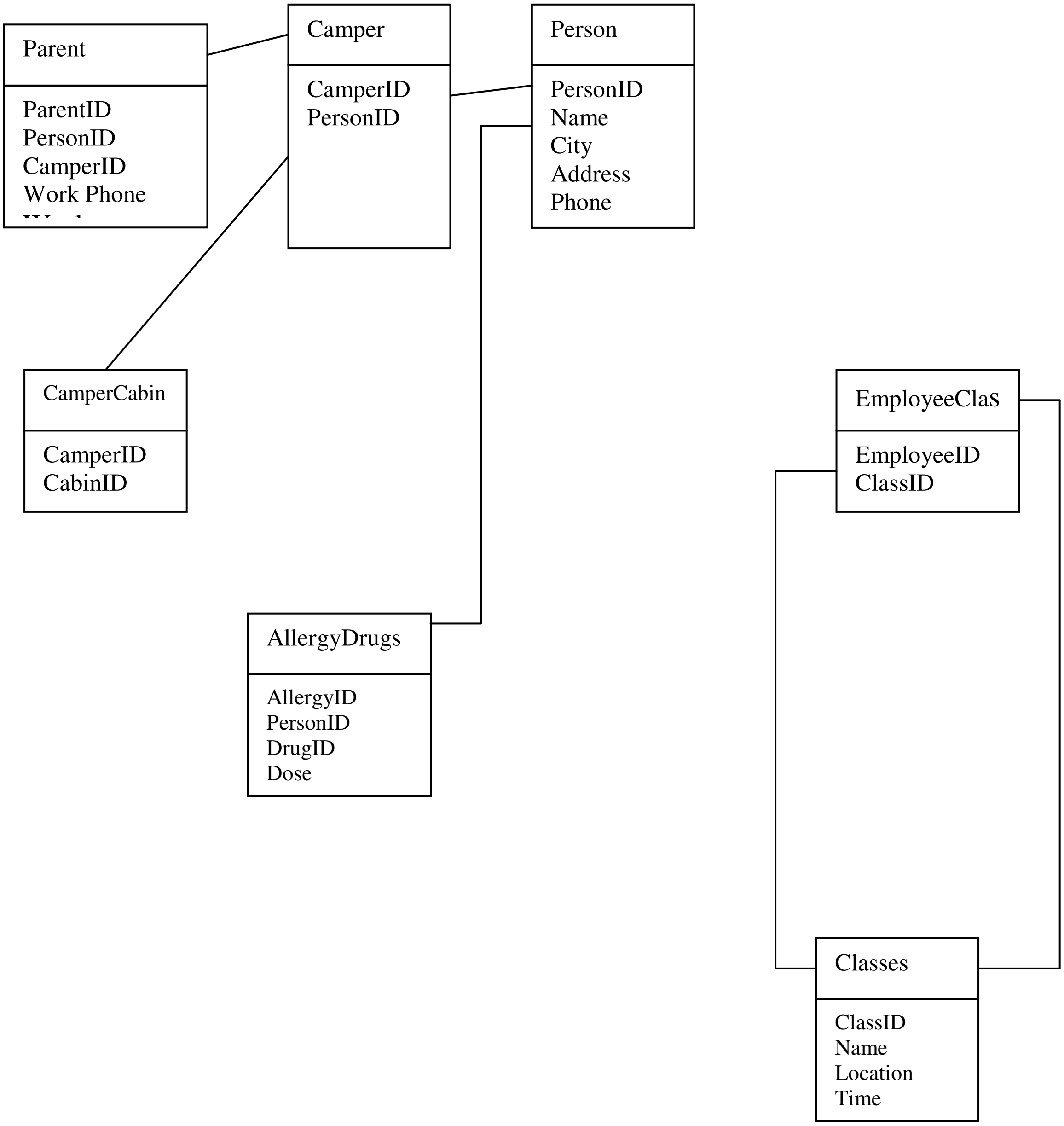
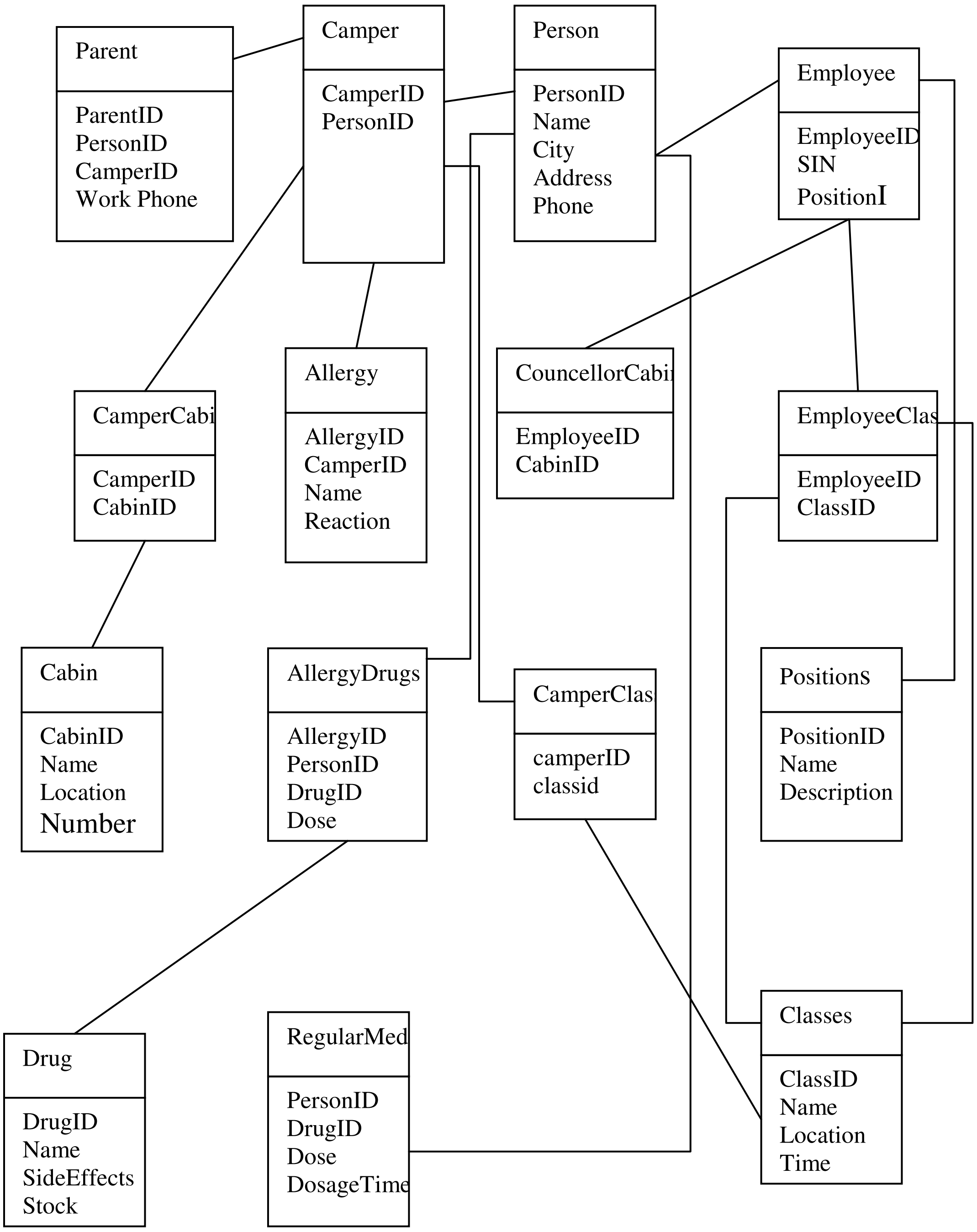


Figure G.1 - Partially completed ER-Diagram provided to participant for them to complete

Complete ER-Diagram displayed by VATagrams

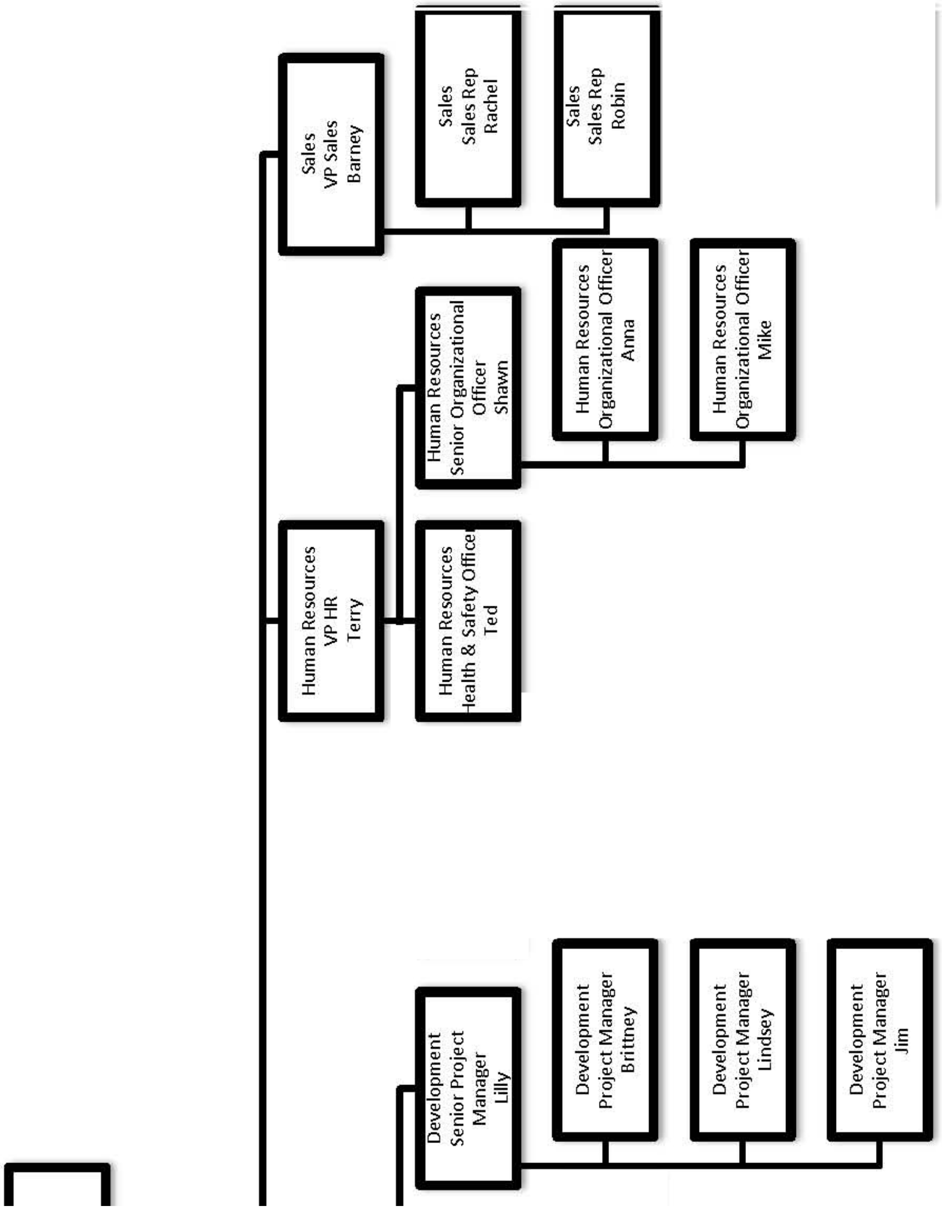
Error!Error!



Parent
ParentID
PersonID
CamperID
Work Phone
Camper
CamperID
PersonID
Person
PersonID
Name
City
Address
Phone
Employee
EmployeeID
SIN
PositionI
CamperCabi
CamperID
CabinID
Allergy
AllergyID
CamperID
Name
Reaction
CouncellorCabi
EmployeeID
CabinID
EmployeeClas
EmployeeID
ClassID
Cabin
CabinID
Name
Location
Number
AllergyDrugs
AllergyID
PersonID
DrugID
Dose
CamperClas
camperID
classid
Positions
PositionID
Name
Description
Drug
DrugID
Name
SideEffects
Stock
RegularMed
PersonID
DrugID
Dose
DosageTime
Classes
ClassID
Name
Location
Time

Figure G.2 - Example of what the completed ER-Diagram may look like from a participant

Organizational Diagram provided to participants in paper form to complete



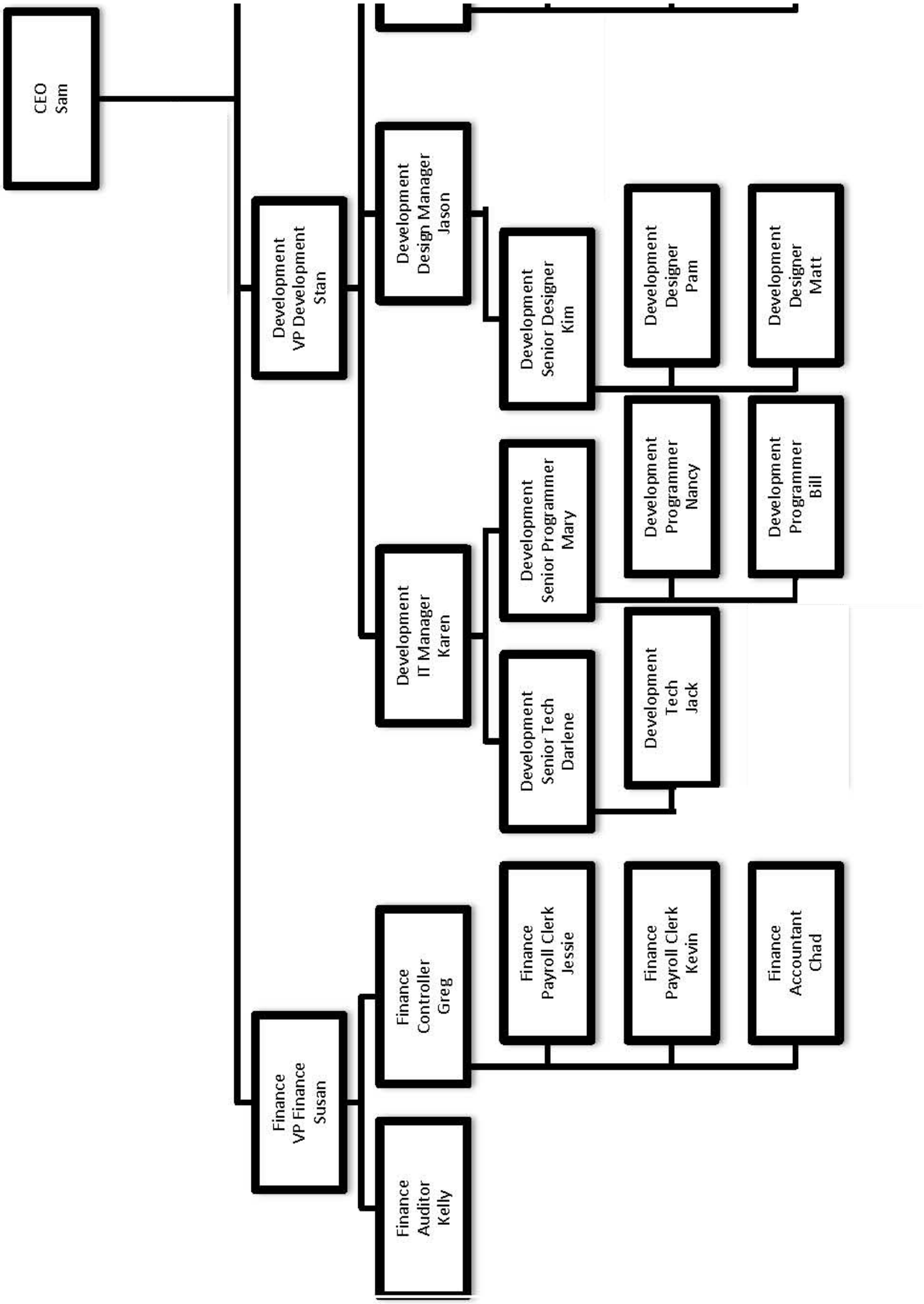


Figure G.3 - Partially completed organizational diagram to be provided to the participant for them to complete

ER-Diagram provided to participants via VATagrams

Refer to Figure D.1

Audio Only Reading Post-testing Questionnaire

1. Gender: M/F
12. What age group are you in?
    - 18-24
    - 25-34
    - 35-44
    - 45-54
    - 55-64
    - 65-74
    - 75 or older
13. Have you had any experience with an iPod Touch, iPhone or iPad?
14. Have you had any experience using other touch screens?

Answer the following questions in regards to the Organizational Diagram:

15. On a scale of 1 – 5 where 1 is extremely difficult , 2 is somewhat difficult, 3 is neither difficult nor easy, 4 is somewhat easy and 5 is extremely easy, How would you rate the following?
    - How easy was it to determine the objects?
      Extremely Difficult Extremely Easy
      1 2 3 4 5
    - How easy was it to determine any attributes?
      Extremely Difficult Extremely Easy
      1 2 3 4 5
    - How easy was it to determine any relationships?
      Extremely Difficult Extremely Easy
      1 2 3 4 5
    - How easy was it to draw the diagram from the information the system provided you?
      Extremely Difficult Extremely Easy

1 2 3 4 5

16. When you compared your drawing to the actual diagram, were there any differences you were surprised about? If yes, please explain.

17. When you compared your drawing to the actual diagram, were there any differences you were not surprised about? If yes, please explain.

Answer the following questions in regards to the ER-Diagram

18. On a scale of 1 – 5 where 1 is extremely difficult , 2 is somewhat difficult, 3 is neither difficult nor easy, 4 is somewhat easy and 5 is extremely easy, How would you rate the following?
    - How easy was it to determine the objects?
      Extremely Difficult Extremely Easy
      1 2 3 4 5

    - How easy was it to determine any attributes?
      Extremely Difficult Extremely Easy
      1 2 3 4 5

    - How easy was it to determine any relationships?
      Extremely Difficult Extremely Easy
      1 2 3 4 5

    - How easy was it to draw the diagram from the information the system provided you?

Extremely Difficult Extremely Easy
1 2 3 4 5

19. When you compared your drawing to the actual diagram, were there any differences you were surprised about? If yes, please explain.

When you compared your drawing to the actual diagram, were there any differences you were not surprised about? If yes, please explain.