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Exploring New Directions In Multi-Modal Spatial Data Access

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Exploring New Directions In Multi-Modal Spatial Data Access

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Exploring New Directions in Multi-Modal Spatial Data Access" submitted by Douglas Hagedorn in partial fulfilment of the requirements of the degree of Master of Science.

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Abstract:

This thesis project uses a three tiered approach to explore new ways to make maps and Geographic Information Systems as accessible and useful for non-sighted people as they are for those with sight. The first tier explores how and why we have experienced difficulty when investigating non-visual cartography and devising innovative mapping strategies. The second tier draws upon critical cartographic theory and promising findings from extant research to propose an interaction-centric approach for research progress. The third tier proposes and demonstrates a prototype non-visual digital mapping system called the Fuse-Map Interface.

Overarching topics include the adverse influence of assumptions and epistemological traditions in non-visual cartography, the importance of reflexive map interactions that enable the synthesis of meaning from representations of spatial data, and novel user interface technologies developed for non-visual human computer interactions. Necessary affordances for non-visual maps and new multi-modal human computer interfaces are also discussed in depth.

Preface:

Beyond wearing prescription glasses, I have not personally experienced any form of blindness or significant vision loss. Nevertheless, in writing this document I wish to emphatically convey my sincere respect for the needs, unique lived experiences, and abilities of those who live with vision impairment. It is my utmost hope that this sentiment is not lost in the assertions, terminology and, most importantly, use of diagrams and visual aids in this thesis.

Although this research project directly addresses the issues and impacts spatial data access faced by blind and visually impaired people, I have chosen to avoid also entering into the broad and meaningful discourse concerning the nature of disability, nomenclature, and perspectives on the continuum between differing social and medical models of disability. By contributing the findings of my thesis to the larger domain of geographic discourse I would, however, like to demonstrate that the scope of geographic activities includes and connects all people, regardless of their physiological or demographic identities. Studies like this one must not serve to create isolated niches of research, but instead inform and inspire further explorations throughout the wider geographic community.

Furthermore, the term ***non-sighted people*** will be used whenever possible to simply denote anyone who cannot adequately and serviceably use a map or geographic product due a condition of complete or partial vision loss. This nature of this term will be discussed in section 1.5.

Although maps and geographic content are the primary form of spatial imagery discussed throughout this thesis, a wide spectrum of alternate spatial information from other disciplines could also be addressed wherever maps are referenced. The limited scope of spatial data types discussed in this thesis is, therefore, intended only to focus and clarify explanations rather than exclude other possible information types. Further research will certainly reveal myriad other spatial data products that could potentially be made more useful and accessible to non-sighted people using the techniques proposed here.

Due to the diverse range of disciplines that contribute to research progress in non-visual cartography (geography, psychology, computer science, etc.) a glossary of key terms has been provided following the last chapter to clarify critical concepts. Terms included in this glossary will be indicated with **bold text.**

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This thesis is dedicated to my parents, Eric and Mavis, who taught me how to create new things with my hands and words.

List of Tables

List of Figures and Illustrations

List of Symbols, Abbreviations & Nomenclature

CNIB – Canadian National Institute for the Blind

GIS – Geographic Information Systems

GUI – Graphical User Interface

HCI – Human Computer Interactions/Human Computer Interface

HRTF – Head Related Transfer Function

ICA – International Cartographic Association

IR – Infrared

IRS – Interactionally Rich Systems

KVM – Keyboard, Video Screen and Mouse

NUI – natural User Interface

OUI – Organic User Interface

ppGIS – Public Participation based Geographic Information Systems

PUI – Perceptual User Interface

RBI – Reality Based Interactions

REA – Requirements Engineering Analysis

TUI – Tangible/Tactile User Interface

VR – Virtual Reality

WIMP – Windows, Icons, Menus and Pointers

XML – Extensible Markup Language

1 Introduction

1.1 Issue

Maps and geographic information sources, such as atlases, globes, GPS devices and web applications, can illustrate spatial phenomena with great clarity and utility; however, access to these products is not universal. Blind and visually impaired individuals are often entirely unable to use these highly pictorial products. Recent reports suggest that nearly 180 million people worldwide live with significant vision impairment, 45 million of whom are completely blind (Lighthouse International 2008). Without sufficient access to spatial information, the capacity for independent mobility, geographic learning and communication concerning spatial concepts may be seriously reduced for non-sighted people, who cannot use traditional visual maps.

In 2005, the Canadian National Institute for the Blind [CNIB] documented a number of direct implications to social integration, employment levels, education, mobility, and recreational opportunities that stem from the unmet needs of non-sighted people. Geographic knowledge is fundamental for success in these areas and many currently inaccessible maps and geographic products are necessary tools to fulfill these unmet needs (Rowell and Ungar 2005). Certain types of maps and diagrams, such as road and pathway maps or building plans, may be used to build self-referenced, or **egocentric,** knowledge for route planning, active navigation and orientation purposes (Lobben 2005). Other map types may be used for spatial analysis or to build **survey knowledge** and an **allocentric** awareness of physical and human landscapes. Examples of the spatial relationships among objects, places and areas expressed by this second category of maps include political territories, migration trends, international trade, climate change patterns, and regionalized thematic or demographic distributions.

The institutional implications of map inaccessibility are substantial. Professor Reginald Gollege (1993), an **adventitiously** blind geographer, asserted in a survey of Geography and the Disabled that individuals with impaired sensory apparatus live in a transformed or distorted space that is experientially very different in its demands and challenges than what is experienced by sighted populations. The disconnect between traditional constructions of geographic information and this transformed world is immense and must be bridged in order to achieve more equitable, meaningful, and universal geographic discourse. Pow (2000) posits that “the persistence of visual ideology is problematic as it encourages geographic scholarship to neglect the role of non-visual senses, while at the same time, marginalizes the experiences of non-sighted people (p.166)". Wies et al. (2001) assert that the inaccessibility of instructional materials, media and technologies used to promote geographic education hinders the abilities of students with little or no sight to excel and freely pursue technical careers. These same educational barriers deny the world access to this potential pool of talent. Challis (2000) also notes that people with unimpaired sight may also experience situations of restricted vision, such as power outages, fog, or smoke and the potential value of non-visual maps is generally overlooked in these instances.

As professionals whose mandates promote building spatial awareness, geographers and cartographers are called upon to provide skills and tools that can illuminate the unique nature of a visually inaccessible world to both the non-sighted and sighted alike. However, these goals have not yet been reached (Vidal-Verdu and Hafez 2007) and non-visual scholarship in cartography is often seemingly marginalized by advances and pressing problems in other areas of the field[1] (Perkins 2002).

In the context of geographic discourse, vision impairment and blindness are conditions of particular significance for those whose lives are made more difficult by the intense emphasis on visual media in contemporary society. This thesis will contribute to the potential improvement of map accessibility for non-sighted people by examining factors that prevent universal access to geographic information and impede the developmental progress of non-visual maps.

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[1] To provide an illustration of this tendency, in MacEacheren's (1995) highly regarded treatise "How Maps Work: Representation, Visualization and Design" approximately 12 out of over 450 pages of written text are concerned with non-visual map issues.

1.2 Research Approach

1.2.1 Problem Statement:

At a fundamental level, the central question guiding this thesis can be stated as follows:

> How is it possible to make maps and digital spatial data platforms as accessible and useful to non-sighted people as they are to those with sight?

This question asks for an exploration of alternative strategies that can achieve the same ends and outputs as visual maps while using unique, user appropriate means. A foreword provided in the Proceedings of the First International Symposium on Maps and Graphics for the Visually Handicapped (Wiedel 1983), explicitly captures this sentiment:

> A primary goal of those who provide spatially portrayed data, in graphic form, is to communicate with those who require or wish to understand the spatial relationships of the information presented. To achieve this goal we must consider methods that will permit the broadening of the range of options of the visually impaired and to strive for eventual equality with the sighted of availability of spatial information.

Beyond responding to the call for research that broadens the range of map options available to non-sighted people, this thesis will also address of the state of non-visual cartographic[2] research to date. Given the limited success of existing non-visual mapping solutions, it is likely that new, unorthodox research approaches and ideological assumptions are necessary. Less conspicuous, perhaps underestimated or unexplored, aspects of the issue may also provide new insights.

I will argue here that the impotence of research efforts thus far has had more to do with the ideological assumptions that are used to generate new types of non-visual maps than it has to do with the functional qualities of the maps themselves. Thus, while reviewing non-visual cartographic research to look for promising findings, I will also critique the nature of the research itself in order to determine better ways to search for and produce non-visual maps. This critique will be carried out in the spirit carefully outlined by Crampton and Krygier (2006), who state:

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[2] Cartography can be broadly defined as the science of preparing all types of maps and charts, and includes every operation from original survey to the final printing of a map (Kubanakubo, 1993). Non-visual cartography can therefore be considered a sub-discipline of cartography concerned entirely with preparing maps and charts intended for use by individuals who cannot see.

> a critique is not a project of finding fault, but an examination of the assumptions of a field of knowledge. Its purpose is to understand and suggest alternatives to the categories of knowledge we use... A critique does not seek to escape from particular categories but rather shows how they came to be and what other possibilities there are (p. 13).

Harris and Harrower (2006) suggest that taking a step back from applied research to investigate how certain categories and assumptions in a field came to be, what they achieve, and what alternatives may exist will help build a more cohesive and powerful research approaches. This investigation will proceed in that spirit.

1.2.2 Objectives

A three tiered approach will be used to facilitate this investigation. The first tier explores why and how we have experienced difficulty when investigating non-visual cartography. As a means to escape these difficulties, the second tier draws upon new critical cartographic theory and promising findings from existing research in order to propose a promising new approach for inquiry in this field. The third tier proposes and demonstrates a prototype non-visual digital mapping system designed using the approach posited in tier two. The tiers of this approach are linked to the corresponding research objectives outlined below:

Objective 1:

> Critically evaluate the history, traditional modes of mapping practice, and guiding assumptions currently at play in non-visual cartographic research in order to suggest alternatives that better promote the development of maps for non-sighted people.

Objective 2:

> Explore the impact and significance of affordances and secondary interactions in the contexts of map use, spatial data perception, and geographic knowledge synthesis.

Objective 3:

> Propose and demonstrate a multi-modal geographic information system designed for non-sighted people that integrates novel accessibility technologies and interactive functionality to promote the synthesis of knowledge from spatial information.

1.3 Premises for Research

The validity of the following premises will be explored throughout the course of this research project in order to fulfill the objectives stated above.

1.3.1 Premise One

Maps can be made more useful and accessible to non-sighted people by replacing the incomplete 'information communication' theoretical model currently prevalent in non-visual cartography with more a comprehensive model proposed by critical cartographers.

Harley and Woodward (1987) state that "maps are geographic representations that facilitate a spatial understanding of things, concepts, conditions, processes or events in the human world." (p. XVI) Understanding the mechanisms that support this facilitation is vital to open the range of map options available to non-sighted people. Various theories that attempt to explain how geographic information is represented and shared have emerged and evolved.

Historically, the genesis of alternative non-visual mapping strategies has been tempered by the most obvious challenges of this problem – the difficulties of communicating geographic information without visual means of representation (Trevelyan 1986). This hypothesis postulates that research conducted in non-visual cartography to date largely assumes the validity of a linear model of cartographic 'information communication'. The information communication theory of map operation is based upon the Shannon-Weaver Model for information transmission through telecommunication devices (Figure 1.1). It proposes that information[3] is conveyed as an encoded data signal from a source to a recipient via an intermediate medium, such as a telephone, television, or, in this case, map. This data signal is presumed to be explicit in that the information

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[3] As a matter of clarification, the terms data, information, and knowledge, will be seen as having distinct meanings in this thesis following the schema provided by Lin et al. (2003 The term spatial data refers to the discrete component particles of content in a map, such as the lines, text, shapes, and figures that represent specific features, coordinates, symbols, labels, and attributes. Information, or spatial information, will refer to the claims that a map or reference source constructs through its data arrangements. For instance "The Prime Meridian passes through a country called England" or "Canada is North of the United States". Spatial knowledge refers to the personal understanding of geography that an individual develops through the uptake of map data and subsequent cognition of information. In essence, geographic knowledge is gained by learning and understanding what information the discrete data arranged in a map depicts.

will be readily internalized by the recipient and subject to degradation from noise and interference.

The primary variables that determine the facilitation of spatial understanding in this model are the quality and quantity of information that is communicated. The recipient faces a prohibitive lack of information if a map cannot successfully communicate its content. Tobin (2008) offers a formulation of this theory as an equation that states:

$$y = f(a,b,c\ldots)$$

In this equation, *y* represents the possible achievements of a non-sighted person (i.e. achieving spatial understanding through map use) and is a function [*f*] of the different kinds of information made available [*a,b,c…*]. Increasing the amount and quality of information a map communicates will serve to increase spatial understanding and vice versa. Research built upon this model is characterized by investigative approaches that are intended to remove the interference and filtering bottlenecks in map designs that mitigate information transmission (MacEacheran 1995) and will be explored in chapters two and three.

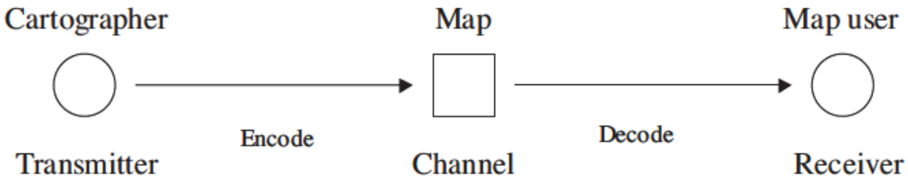

Figure 1.1 The Generalized Information Communication Cartographic Model (Kitchin, Perkins and Dodge 2009) (p. 6)

While this model has been eschewed in visual cartography in favor of more comprehensive theories (MacEacheran 1995, Edney 2007b), its continued prevalence in non-visual research may have hindered progress in this area. One possible explanation for this divide is that many of the researchers engaged in making maps for non-sighted people are typically not professional cartographers and geographers in the strictest sense (Lobben 2005). Rather, they are the engineers, teachers, computer scientists, graphic designers, and personal aids, whose skills are absolutely necessary to make these innovative products, but who may not be thoroughly versed in the current cartographic theory. Groups that promote research in this field are not just those directly affected by the challenges blindness and vision impairment present, but also include members of the public who work in a variety of organizations. Furthermore, the discovery and utilization of new technologies for map making currently outstrips the rate of advancement and availability of cartographic theory (Kraak 2007, Andrienko, Andrienko and Voss 2002a). A trend has emerged from this where cartographic techniques are not informed by cartographic theory.

In recent years a number of scholars have employed the principles of critical inquiry to challenge the central ideologies of cartography, mainly in the visual context. Their movement has deconstructed and reinterpreted the mechanisms that enable maps to serve as facilitators of shared understanding. According to Corner (1999), cartographic theory has been hampered by a preoccupation with viewing maps in terms of what they represent, rather than what they do. He suggests that the function of maps is not to depict but enable. As such, the facilitation of spatial understanding is dependent on both the information available and how it can be engaged and used. Maps do not simply represent the geographic world for the purposes of communal information storage and retrieval (Andrienko et al. 2002a). They are also, more importantly, **ontogenic** tools that *afford* the synthesis of knowledge (Kitchin 2008), to build personal understandings of spatial phenomena. Aldrich et al. (2003) note that two faces of mapping must be recognized – cartography and **cartographicacy**. The former is concerned with how maps are produced and the latter is concerned with how maps are consumed and their content read, mentally digested, reconstituted, referenced and shared.

The critical reinterpretation of cartographic operation seeks to transcend the perspective that maps are presenters of stable, self-evident information. Maps are instead recast as explorable data-rich scenes from which personal knowledge is synthesized through geographic thinking, interpretive activities, and experiential engagement with map content. Kitchen and Dodge (2007) state that the value maps have as vehicles for information dissemination emerges from the fact that they are tools for learning. They quote Star and Ruhleder (1996) to emphasize that maps become tools “in practice, when connected to some particular activity” (p. 337). In this sense, maps can be seen as components of a cartographic information system. Schneider and Strothotte (2000) stress that:

> Information systems in general and those for blind people in particular put the user primarily in the role of a recipient of information. For example, a search for information on the web can be considered successful if a page has been found with all the required data presented in a succinct form. Indeed, many users

> complete their search by printing out a page or a small number of selected pages. By contrast, students are taught not only by presenting material to them, but also by letting them actively work with it. For example, every good mathematics book will give exercises for the student to practice what they have learned (p.188).

By casting the non-sighted map user only as an information recipient, systems that reflect the information communication paradigm prevent individuals from reaching a more beneficial state of learning. Schneider and Strothotte’s comments intimate that cartographicacy should be refined and taught so that users can engage maps and construct meaning from spatial data by actively practicing their learning. Opportunities to practice cartographicacy involve a wide range of ‘mapping’ activities or secondary interactions, which are those that follow the initial exploratory interactions needed to initially detect and collect sensory stimuli from a map. It is insufficient to only devise and optimize ways to make data apparent and discoverable for the map user. Particular secondary interactions that allow knowledge and understanding to be constructed from apparent data are necessary as well.

In this thesis I will argue that, in addition to known cartographic variables, cartographicacy and the affordance qualities of maps provide another set of equally important yet under recognized variables for non-visual cartographic information systems. These variables determine how a map can be used and provide opportunities to contextualize and interpret salient information via reflexive engagement. A new equation can be formulated based on this premise:

$$y = f((a,b,c...)(P_1,P_2,P_{3...}))$$

In this equation, the possible achievements of a non-sighted person [y] are a function of the information available multiplied by the different practices [P_1 ,P_2, $P_{3...}$] a map affords to negotiate meaning from the representation. If information is unavailable [a,b *or* $c…$ = 0] or cannot be used to synthesize knowledge [$P_1,P_2,$*or* $P_{3...}$ = 0] then understanding will not be achieved.

Approaches that focus solely on improving information representation without understanding information engagement practices, as has previously been the case throughout the history of non-visual cartographic research, will hinder the development of new maps for non-sighted people. Unfortunately, due to the predominance of the information communication paradigm a pervasive awareness of the variables of cartographicacy [$U_1, U_2, U_{3\ldots}$], the secondary interactions and the affordance value of maps, has not yet been cultivated and cannot yet be elevated.

1.3.2 Premise Two

Maps can be made more accessible and useful for non-sighted people by identifying and integrating important secondary interactions that facilitate the synthesis of personal knowledge from spatial data. One critical secondary interaction is the ability to conspicuously alter a map and/or collocate and overlay multiple layers of information without occluding or disturbing the original representation.

As digital technologies pioneered for **Geographic Information Systems** [GIS] in the latter half of the twentieth century are refined in the twenty-first, an era of unprecedented map interactivity has seemingly emerged. Meng (2003) posits that “the boundary between map making and map use has been increasingly blurred since the introduction of interactivity into the cartographic process (p.1).” However, I would argue that interactivity itself was not actually recently introduced, nor is it a novel or unprecedented component of the cartographic process. Although personal computing technologies and creative software functions allow us to access, manipulate, and explore maps in many powerful new ways, the interactive relationship between map and user is neither as new nor bounded as they may seem. However, pre-digital examples of map engagement interactions often go unnoticed.

Secondary interactions in the visual context are often so subtle, ephemeral, or common place that they seemingly warrant little merit for investigation. Yet these behaviours are universal enough that British photographer Steven Gill captured them as the subject of a complete photo-essay (Ronson 2004) (Figure 1.2). Without seeing the content on the page in these images it is still easy to recognize the gestures used for mapping activities. Even the most exhaustive investigator would be hard pressed to find someone who, when using a map, did not point with their finger to a feature of interest, circle or highlight a destination, draw a line along an intended route, place a pushpin to represent an incident or point of interest, attach adhesive notes with extra information, make folds to compare distant sections more closely, or tally and calculate the distances among particular locations on a route. Mearleau-Ponty (in Ackerman 2009) observed that vision also exists in the context of the movement of the eyes and is thus, in ways, gestural. The patterns, targets, and paths that are traced by the eyes act like a form of touch, in that they are directed and allow viewers to negotiate and control the flow and focus of perceived information through the movements of their gaze.

Figure 1.2 Images from Field Studies (Gill and Ronson 2005)

Briefly consider a selection of scenarios where information is synthesized from a map ‘at hand.’ A concierge at a hotel will immediately put pen to paper to create dots, circles or lines that identify and highlight nearby shops and restaurants on a pre-printed map for guests. When planning a trip by car, many will use a highlighter to trace a route along a particular road and perhaps certain ports of call along the way, and will typically fold a map to isolate a focal region on the page. One would never confuse a dog eared and marked map that has been along for the ride on a family vacation with the pristine copies for sale in a shop. World maps in countless youth hostels are physically stuck with pins to represent the homes of visitors. Explorers and scientists alike will litter fresh maps with field notes, routes, sites, and waypoints. Elementary classrooms often have continental wall charts plastered with photos and objects that represent certain countries and inspire children to identify and explore the idiosyncrasies associated with each place and region. A sailor plotting a ship’s course will use a divider to measure distance on a chart or a parallel rule and compass to transfer a course bearing. Indeed, there are many seamanship skills, clear examples of secondary interactions, which must be learned before a nautical chart can be used as a tool with which to plot a course and pilot a boat. Each of these actions represents a practice that transforms the map from a mere aesthetic representation of a spatial dataset into a useful tool for knowledge construction.

Aitken (2009) asserts that "there is a power to maps that is about what they are and what they do" (p.1). In addition to presenting information, maps can be used in ways that isolate, juxtapose, or emphasize particularly salient features and give them new relevance. What does this mean for the quest towards viable non-visual maps? Simply that we must investigate not only how maps represent data but also how they actively mediate it in order to negotiate new meaning. While it cannot be denied that there is a significant value to maps in their capacity to distribute data among a wide audience, it is the secondary processes in this exchange that are essential to enable and facilitate a shared understanding (Guelke 1976). The fact that these interactions are often noticeable by other map observers makes them tremendously powerful. For instance, a lecturer who points a laser pointer at a map projected in front of an audience immediately but temporarily alters the meaning of that map for both himself and his audience. It changes from a representation where all features are neutral and equally significant to one where highlighted features stand out among the now contextualized surrounding features.

Yet because they are neither concrete nor predicable the investigation of interactions that support knowledge synthesis have been largely postponed to focus on the half of the problem that lends itself well to scientific investigation: how is information that is well suited for visual depiction otherwise represented when sight is limited or unavailable? In a literature review of work contributing to research in the field of non-visual cartography, very little research can be found that addresses the secondary interactions through which new interpretations and meaning are constructed after data has been identified or 'transmitted'.

When map interactivity is addressed most research has instead focused on interactions for data exploration or the processes involved in refining the content a map presents, which may include things like panning, zooming, or selecting layers (Harrower 2009). Yet these interactions largely amount to different ways of *requesting* information from a dataset. Often, they are simply automations of tasks that would have otherwise been performed manually with physical tools, such as a magnifying glass or ruler. Table 1-1 outlines various literal expressions describing the 'request' interactions that exemplify the new types of map interactivity computers provide.

Primary Map Interaction	Literal Expression
Panning	I would like to see what is next to the area I'm exploring.
Zooming	I would like to explore a larger area in less detail or a smaller area in more detail.
Deactivating Layers	I would like to see only information about roads.
Activating Layers	In addition to road networks, I would also like to see buildings.
Identification	I would like to know the location/coordinates of this particular feature.
Measurement	I would like to know the distance between location A and Location B.

Table 1-1 Literal expressions of common map interactions

These interactions do not encompass the ways in which users impose themselves on a map to synthesize content and learn by doing. Achieving successful non-visual cartography is a synergistic endeavour between map and user. The true relationship between maps and map users is neither passive nor one directional. Various secondary interactions performed after map representations have been perceived allow users to impose personalized information structures onto abstract data and synthesize new meaning. These interactions allow us to make interpretations about presented data, construct new knowledge, and organize hierarchies for specific pieces of information within our attention. We apply order, create structure and actively interact with the medium upon which our desired information sits and do many other recontextualizing tasks to isolate, emphasize and structure the information we need within the surrounding array of content.

Unfortunately, due to the nature of visual impairment, many well practiced map design and editing methods are not viable for non-sighted people. Much of the essential power of a map is derived from the ability to display a relationship between two features or attributes that occur in the same location. Often, in visual maps and GISs, this is achieved using transparency or the superimposition of two designs as well as database linkages. According to Meng (2008), cartographers must use techniques such as these in order to overcome the inherently limited size of map display surfaces which can only hold a limited number of symbols. By making particular symbols transparent, contextually anchored or linked to additional data, extra information is hidden within the display surface. However, information hiding techniques must be coupled with information revealing techniques.

Much of the difficulty for non-visual cartography lies in the fact that there are no convenient analogues for the previously mentioned techniques. Layering information or marking up a map with ink requires transparency or highly tuned sensory discretion so that opaque markings do not obscure the original. There are few ways of painting or placing physical markers upon tactile maps that do not temporarily or physically occlude the underlying information. Although there are several known **surface tactile phenomena** (Merleau-Ponty 2002), such as dampness, oiliness, stickyness, or compressability, that could be used to annotate the physical form of an object, no viable methods to create tactile maps using these phenomena exist yet. Likewise, the superimposition of features is not easily achieved without **synoptic perception** and most non-visual modes of exploration are inherently **serial**.

Despite the investigative fervour in non-visual cartography no system for mapping has been devised that affords non-sighted people the ability to imprint personal abstractions upon a map. More often than not, there is a disproportionate research focus on information transmission at the expense of understanding. Studies of this type often proceed by manipulating a certain map design parameter and then testing the subsequent volume of data a user can extract and the quality of their mentally amassed data for problem solving. They do not often test how the map actively facilitates learning or purposeful problem solving during use unless it is to travel along a route using a map to navigate. The difficulty with this incomplete accounting of map interaction is that it has generally not informed the development of new map products that are intended for non-visual use, so only half of the issue is addressed.

1.3.3 Premise Three

Maps can be made more accessible to non-sighted people via interactive computer systems that integrate novel tangible, natural, and perceptual user interface technologies and functional separation premises.

The interactivity computers provide for exploring geographic information has long been lauded as a breakthrough by many for serving the needs of non-sighted people (Levesque 2005, Burger 1994). Computers can consolidate a large volume of map documents that would otherwise be difficult to store and organize as tactile hard copy. They can provide rich representations of data using many different feedback channels. A computer connected to the internet can download new editions of digital maps to stay up-to-date and can enable geographic discussion and sharing among many distant people. GIS software can provide powerful map rendering and exploration tools that automate complex tasks and carry the computational loads that far exceed human capacities. Yet for all these valuable qualities, computers have not yet provided the means to fully meet the needs of non-sighted people (Vidal-Verdu and Hafez 2007). The functionality of most commercialized human-computer interface designs limits the utility of these systems for non-sighted people. To this end, Mark Harrower (2009) states,

> The success of interactive maps depends in large part on the interface – not just the map itself. The interface defines both the functionality of the map – what the map can do for the user – and the learning curve – how quickly the user harnesses that functionality. At the heart of many problems people encounter when using interactive maps is a mismatch between the capabilities of the system and the expectations of the user conditioned by their previous experiences with interactive maps (or lack thereof) (p. 4).

This mismatch is most apparent in the design of the personal computer found in the vast majority of homes, offices, and stores. This style of computer channels input and output through a keyboard, mouse/touchpad, monitor and speakers and operates using a Graphical User Interface [GUI] that typically employs a schema of windows, icons, menus and pointers. Various hardware peripherals (printers, scanners, storage devices, etc.) and software may be installed to modify or extend a computer’s input/output capacities or functional abilities. Despite this morphological flexibility, the archetypal personal computer people encounter most often remains relatively unvaried and uniform.

Personal computer accessibility, particularly for mapping purposes, remains limited even with accessibility features (Shinohara 2006), such as talking screen readers, Braille type interfaces, and speech dictation programs, which allow non-sighted users to create text documents, use email or instant messaging, and browse the internet. Standard mice do not operate within an absolute frame of reference or provide **haptic** feedback to convey the location of an on-screen pointer. This can cause disorientation for the user especially when switching between a keyboard and mouse. Of late, a style of touch screen interface used for mobile phones and tablet computers has emerged as a growing sector of the computing electronics market, but these devices are generally also designed around a graphical operating system and lack the types of tactile feedback non-sighted users need.

Although many niche and prototype computing devices for non-visual map access have been developed and tested in laboratory settings, none have yet achieved a degree of information access comparable to standard visual products. A more in-depth review of these devices will be provided in chapter three and Appendix A. The majority of these devices have been engineered with the singular goal of making map data more apparent and perceptible. These devices encode and transmit signals that represent map content through sensory channels that are not typically used by personal computers. However, the degree of secondary interaction most niche interfaces can or are intended to provide is minimal.

Another critical issue that has impaired previous attempts to enable non-visual map access on personal computers is the tendency for confusion that occurs when all direct actions and feedback stimuli involved in exploring and manipulating an unseen map are channelled indiscriminately through a user's hands, fingertips, and ears. Confusion may be compounded by the need to hold or grasp a mouse or haptic device, often in only one hand (Ackerman 2009). Although these tools and probes may expand exploratory experiences they simultaneously monopolizes **cutaneous sensations**, limit the users **sensory aperture**, enforces one-handed exploration, and obscures the spatial frame of reference of a map[4].

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[4] Ackerman notes that haptic tools and probes used for non-visual exploration, such as canes, paradoxically both extend and mediate perceptual capacities. When a tool like a cane is incorporated into the sensory system it augments the user's perceptual reach but filters the physical properties that are detected.

To move beyond the mainstream interface paradigm that so poorly serves the needs of non-sighted people different interface design architectures will be needed. Three novel trends in computing, referred to as Tangible User Interfaces [TUI], Perceptual User Interfaces [PUI], and Natural User Interfaces [NUI] offer potential to alleviate the mismatch between users' intentions and their computers' design parameters (Rauterberg 1999, Turk and Robertson 2000). According to Turk and Robertson (2000) these user interface styles are:

> …characterized by interaction techniques that combine an understanding of natural human capabilities (particularly communication, motor, cognitive and perceptual skills) with computer input/output devices and machine perception and reasoning. They seek to make the user interface more natural and compelling by taking advantage of the ways in which people naturally interact with each other and the world. Devices and sensors should be transparent and passive if possible and machines should perceive relevant human communication channels as well as generate output that is naturally understood (p. 33).

The utility of these design concepts for non-visual map access is tremendous because they build upon and augment the user's own body and abilities to operate the system, rather than attempting to couple a standard computer's outward design to a user's unique abilities and physiology. In terms of new opportunities to afford secondary interactions for mapping, these interface styles open the door for many computing actions and activities that are not available with current computer systems.

TUIs allow users employ physical embodiments of digital information to create create systems that eschew abstract virtual renderings or metaphors. They may simply interact with familiar objects in an intuitive manner. These systems often use meaningful props and familiar items, known as **effectors**, to represent or control data. Items such as toys, musical instruments, pens, rulers, books, or notepads may be augmented with sensors and used to engage digital scenes in a way that is meaningfully familiar, more immediate, and less abstract than is the case with many GUIs or virtual interface components. The physical presence and behaviours of these objects can provide very concrete feedback that is desirable for non-sighted users. For instance, instead of using a mouse or entering keyboard commands to move an **avatar** through a map scene, an individual using a TUI could simply pick up and move a figurine across a map on a surface that senses its locations (Figure 1.3). Some tangible objects used in experimental non-visual systems also have the ability to move themselves independently and can guide the user through arrangements of data (Riedenklau, Hermann and Ritter 2010a).

Figure 1.3 Exploring an auditory map by moving a rotating a virtual artefact (Pielot et al. 2007). By changing the direction and location of the duck toy within the map field, the user is able to explore new spatial audio components of a virtual landscape. Loud sounds that are heard through the left ear in one location may become faint sounds in the background when the toy is moved away from that position.

PUIs use computer vision and motion capture technologies to track the movement, positions and gestures of an individual's body as a form of input, rather than requiring the user to manipulate a computer peripheral like a mouse. This allows the user to rely on their body's own proprioceptive sensations for feedback rather than receiving artificial system feedback from the computer. For instance, a PUI system may follow the movement of a user's hand across a table instead of tracking the movement of a mouse or puck that a user moves across a table to guide an onscreen cursor or avatar. Recently released gaming systems such as the Nintendo Wii (Iwata 2010), Playstation Move Bundle (Sony 2010), and Microsoft Xbox Kinect Kit (Microsoft 2010) have successfully demonstrated PUI architectures in commercially available products.

NUIs are human-computer interfaces that are, or can become with training effectively imperceptible to the user. This effect of imperceptibility allows the user to effortlessly engage a digital environment, explore content and use computer applications without the intruding mediations of physical hardware or software clients. An implicit component of the NUI philosophy is a central emphasis on providing intuitive, uncomplicated interactions. For instance, an NUI has been employed if lights and a computer turn on automatically when someone enters a room and sits down at their desk. To provide a mapping example, a map presented on a **multi-touch** surface will allow a user to move a map scene by dragging a finger in the same way that one would move a sheet of paper across a table (Figure 1.4). Alternatively, a **location-aware**

NUI will automatically center a map at the user’s current location, so that they do not need complete extra tasks to begin exploring from their point of reference.

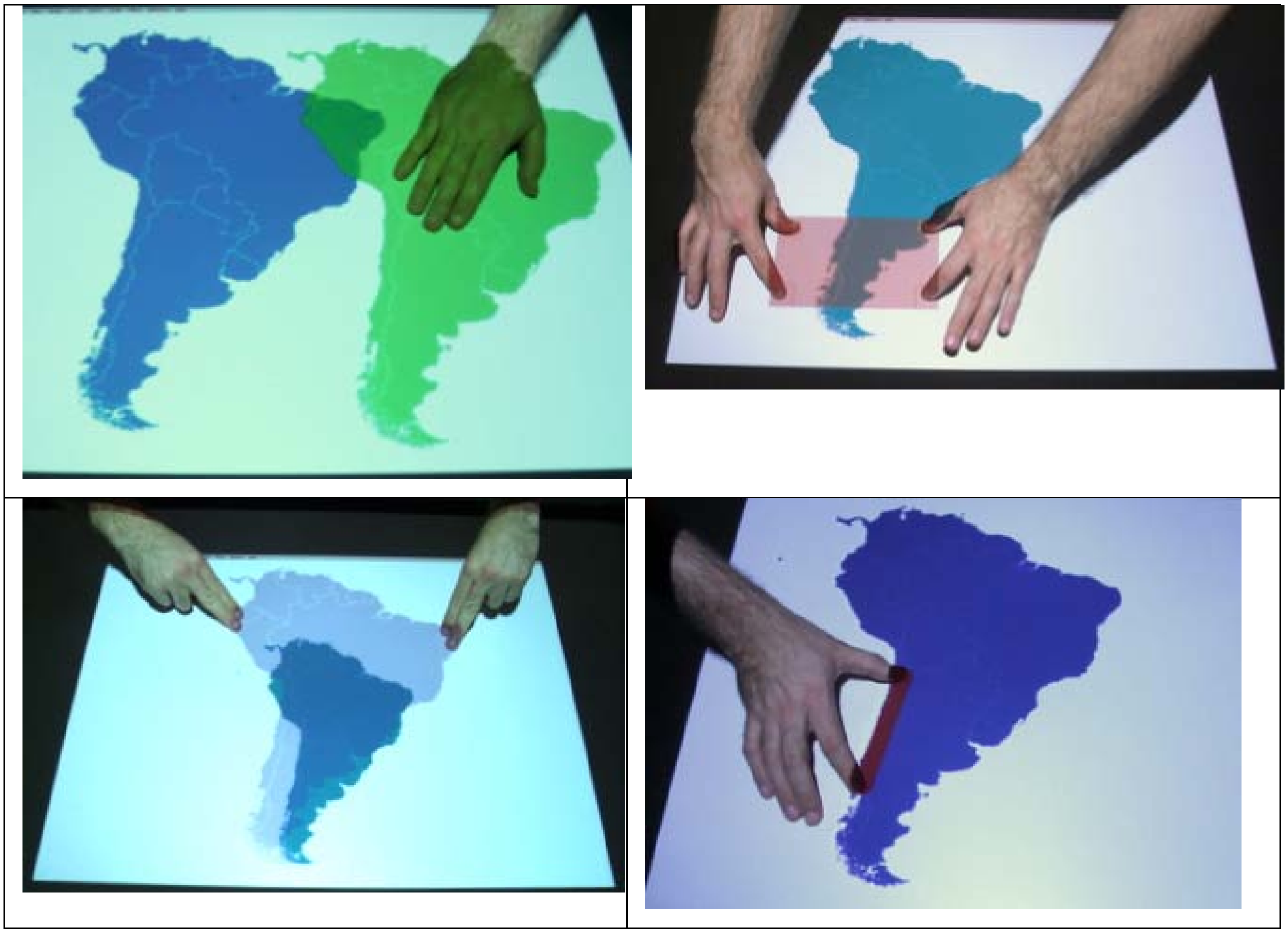

Figure 1.4 Examples of multi-touch interactions linked to commands described in Table 1-1: Top Left - panning, Top Right - Selection, Bottom Left - Zooming, Bottom Right - Measurement

While alternative user interfaces like these cultivate many new options for secondary interactions when exploring and manipulating information on computers, understanding the demands a computer system places on a user is paramount. As the speed of interaction and flow of stimuli between computer and user increases, thoughtful consideration is needed to ensure that confusion is not caused by an overload of information and activity. Elegantly orchestrating system functionality to separate interface input and output activities across different **modalities** is one way to reduce the chance of cognitive overload. The concept of functional separation, used for that purpose in this study builds upon Cognitive Load and Multiple Resource theories (Mayer and Moreno 2003, Oviatt 2006a, Oviatt, Coulston and Lunsford 2004, Wickens and Baker 1995, Jeong and Gluck 2003)

Cognitive load theory posits that the human brain possesses a finite working memory for cognitive processing and that only a certain volume of information flow can be maintained before confusion or memory loss occurs. Multiple Resource theory postulates that because various sensory functions are processed in different locations of the brain, cognitive processing capacity can be increased by distributing tasks among different brain centers. A person's effective information/stimulus processing capacity can therefore be maximized by encoding and distributing information across multiple sensory modalities and body channels. Multi-modal separation of data input and output functions minimizes the amount of cognitive load placed upon each of a user's perceptive memory and kinesthetic control centers and thus increases processing capacity. It is expected that integrating functional separation in computer systems meant for non-sighted people will lead to better uptake of presented cartographic information as well as less user frustration when using the computer system (Mayer and Moreno 2003).

A parallel example of functional separation can be described with a motorist driving and navigating a car. In this scenario, functional separation is employed to control the car by using one hand to steer and another to shift the transmission, one foot to accelerate and brake and another to depress a clutch. To navigate, the driver visually scans the road and surrounding traffic while perhaps simultaneously listening for directions from passenger or GPS device. Additionally, the driver receives feedback through alternate sensory modalities when driving the car, by feeling the position of the wheel in hand and accelerator underfoot and noting sensations weight shifting or transferred road vibration. The separation of unique actions and perceptions across different modes of activity (i.e. steering, shifting, accelerating, braking, signalling), in combination with the provision of meaningfully differentiated sensory feedback, allows a driver to intuitively and successfully drive a vehicle without confusion.

The greatest clarity of understanding, in regards to the perception and cognition of the sensory stimuli, is achieved through meaningful constructions of stimulus events. Working knowledge must be synthesized from sensory feedback provided in response to user actions. When developing a non-visual computer system for geographic learning, if richer and more meaningful sensory feedback can be obtained from intuitive and intrinsically spatial user interactions, then better mental inferences can be made regarding the content of an unseen map.

1.4 Organization of Thesis

In addition to the general introduction and conclusion, chapters 1 and 7 respectively, this thesis consists of six chapters that are conceptually linked in their sequence to the three tiers of the research approach outlined above.

Chapter one introduces the central problem, three focal hypotheses, and objectives of this investigation. It also outlines the progression of the investigation and various bounding parameters.

Chapter two assesses the influence of particular theoretical traditions and research approaches in non-visual cartographic discourse.

Chapter three provides a review of existing research foundations and findings in non-visual cartography to identify promising opportunities for map advancement and highlight research that demonstrates a paradigm of information conveyance research.

Chapter four draws upon existing literature and research concerning non-visual products for geography, using an **interactionally rich systems analysis** approach, to determine or identify the affordances that are most desirable for an ideal non-visual map.

Chapter five presents the design of a novel computer platform for non-visual cartography presentation that demonstrates the traits identified as desirable in chapter four. This system will be referred to as the Functionally Separated Multi-Modal Map Rendering System or Fuse Map.

Chapter six documents the methods and observations of demonstration activities performed to validate the capacities for geographic learning of the system outlined in chapter five.

Chapter Seven addresses the hypotheses treated in this investigation to offer both theoretical and methodological insight towards achieving more effective research practices in non-visual cartography. This chapter concludes by identifying avenues for future research and providing closing remarks.

1.5 Considerations of Blindness and Vision Impairment

Blindness and visual impairment are not unfamiliar concepts to the general public and most people possess a reasonable but basic understanding of these conditions. However, the highly varied nature of vision loss means that there is much unacknowledged heterogeneity in the non-sighted population. It is, therefore, difficult but necessary to construct a concrete definition to replace naive impressions of vision impairment. Furthermore, a definition that describes blindness still cannot provide a sighted person with authentic experiences of a life without vision. This fact necessitates a great deal of sensitivity to the subjectivity of unique and highly personal realities and lived experiences. Nevertheless, an adequately focused characterization of this condition is needed to proceed with an investigation that directly addresses the needs of non-sighted people.

Historically there has been much debate about what constitutes a condition of blindness as well as what capacities and needs can be attributed to non-sighted people (Thompson and Chronicle 2006). This is particularly complex when considering the potential differences among those who are blind from birth (congenital blindness) and those who lose some or all of their sight after many years of visual experience (adventitious blindness). Social constructions of blindness vary intensely. Consensus on the possible physiological distinctions linked to early and late onset blindness, such as brain plasticity and sensory compensation, have not yet been reached, and legal definitions may be contested or highly context sensitive.

Given that distinguishing between the properties of corrected, partial and absent vision is often a matter of degrees among several factors, it may be useful to suggest a diagrammatic metaphor. In this metaphor the domain that encompasses all instances of significant vision loss is represented by a cube (Figure 1.5). Three different factors related to vision loss can be expressed along the axes of this cube: severity of vision loss, visual experience prior to the loss of sight, and non-visual experience after the loss of sight. While observations about blindness garnered from a single individual may not be universal to all non-sighted people, understandings about closely positioned individuals within the cube can be generalized from the experiences of those with similar attribute positions. It is also important to note that an individual’s position is not static and will change with fluctuations in impairment, lived experience and adaptation to impairment.

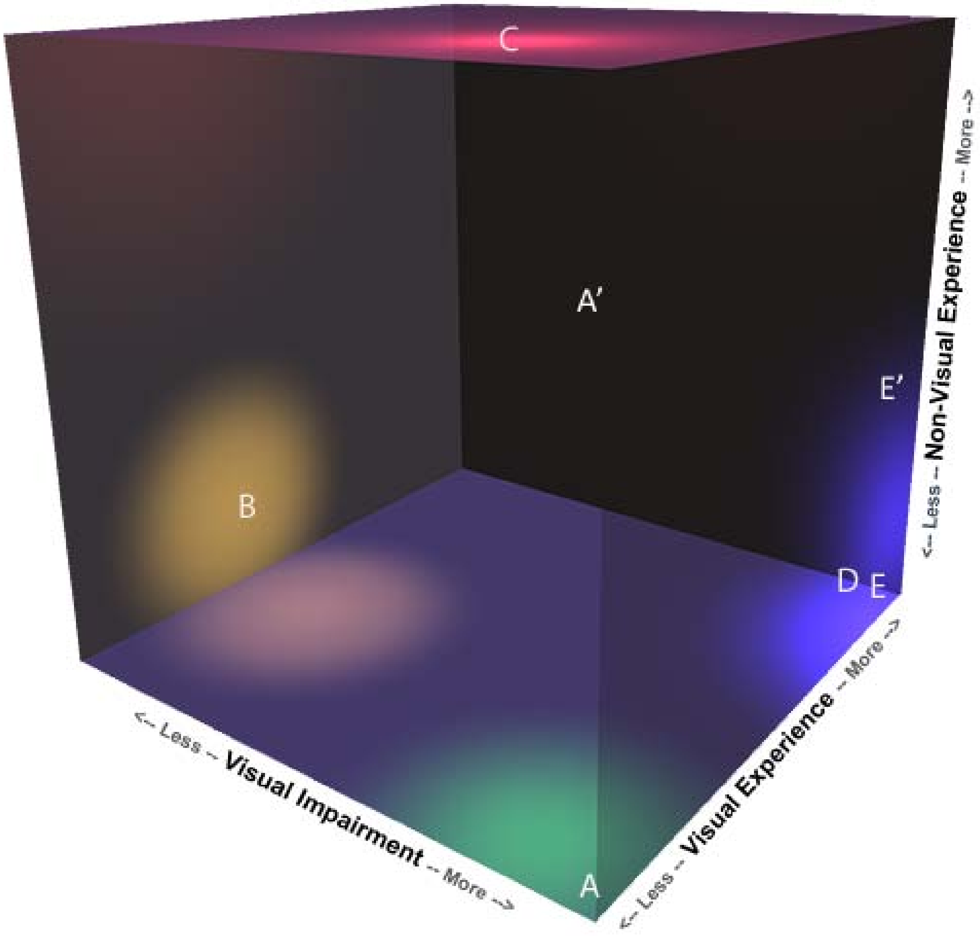

Figure 1.5 Illustrated metaphor for the domain significant vision impairment

Instance	**Visual Impairment**	**Visual Experience**	**Non-Visual Experience**
A: Blind Child	Total impairment	No visual experience	No non-visual experience
A’ : Blind Teenager	Total impairment	No visual experience	Extensive non-visual experience
B: Low-vision adolescent	Low vision	Some visual experience	Some non-visual experience
C: Adult with late on-set vision loss	Some residual vision	Some visual experience	Extensive non-visual experience
D: Adult lost in Fog or Darkness	High impairment	Extensive visual experience	No non-visual experience
E: Newly Simulated Blindness	Total impairment	Extensive visual experience	No non-visual experience
E’ – Experienced Simulated Blindness	Total Impairment	Extensive visual experience	Some non-visual experience

Degree of visual impairment denotes to a person’s physiological ability to perceive and sense visual stimuli. This dimension ranges from low residual vision, which is degraded eyesight that cannot be corrected to normal via prescription eyewear or medical treatment (Thaw 2005), to no vision whatsoever. Low vision may vary greatly within a population yet those with different forms of residual vision may have a categorically equivalent amount of visual acuity. For instance, someone who can only detect differences between contrasting colours and someone who can only see light and shadows may have an equivalent degree of functional sight. Together, both of these levels of partial impairment provide more functional sight than someone who perceives only total darkness but less than someone who has an extremely reduced but relatively clear field of vision. In the context of map use, variations along this dimension may define how much and what type of assistance an individual needs to perceive the features represented on a map as well as which secondary interactions for interpretation may be most viable.

The second dimension, age of onset, refers to the amount of visual experience and developmental progression an individual accrued before losing their sight. Studies report that there are physiological and cognitive capacities that correspond to accrued visual experience before vision loss (Millar 1994, Röder, Rösler and Spence 2004, Wan et al. 2010). For instance, children who are born congenitally blind may not have visual memories or perhaps even fully stimulated cerebral imaging centers that can be called upon to furnish mental depictions of spatial information. Conversely, an individual who has lost sight adventitiously later in life will have collected a wealth of visual memories and mental imagery with which to interpret and process spatial scenes, even though they can no longer perceive visual stimuli. This dimension defines what map content and schemas are meaningful to the user and how knowledge claims must be constructed in order to resonate with the user’s own understanding and knowledge of space and geography.

The final dimension, accrued non-visual experience, denotes the amount of time that an individual has had to adjust to life without sight. The adaptation that can take place over time may include learned habits and skills like Braille literacy or touch typing; familiarization with accessibility aids and technologies like screen readers or touch tablets; as well as physiological compensations like improved hearing acuity or **kinesthetic** perception (Wan et al. 2010, Gougoux et al. 2004). In the context of non-visual map use, this dimension impacts many parameters regarding how a non-visual computer mapping system may operate.

A number of examples are depicted in Figure 1.1to illustrate the metaphor used here. All the following hypothetical persons could each be described as non-sighted in some sense, even though their situations vary considerably. Person A represents a young child born without sight. This child has a high degree of impairment, no accumulated visual experience, and little non-visual experience. She may develop atypical cognitive capacities in comparison to sighted children and may learn non-visual skills more quickly than someone transitioning from a sighted to non-sighted life. As this child ages, her position within the domain will change as more non-visual experience is accrued (as shown by instance A').

Person B represents an adult who experienced partial vision loss as a child. This person has some significant impairment without complete vision loss, a small stock of visual experience to draw upon, and has well developed skills for living without vision. The residual vision this person possesses may allow them to find a computer upon which a map is displayed with relative ease and explore it using a fine sense of touch, but may still need interactive assistance to discern, manipulate, and interpret detailed map content.

Person C represents an individual with a severe degenerative eye disease who has rapidly lost sight late in life. This person has a large supply of visual experience and memories to draw upon but very little familiarity with accessibility technologies and almost no sight remaining. When first using a non-visual map, this person will experience a steep learning curve and will require information to be rendered in a very clear and concise manner. The secondary interactions that allow information to be processed completely will be entirely novel and may require clear explanation, training and a period of adaptive trial and error in order to eventually comprehend the scene a map displays.

Person D represents an adult lost in thick fog or darkness. While external factors cause this person's vision impairment, they are nevertheless temporarily unable to use their eyes for any useful sensory exploration. This person will have a severe level of impairment, a large store of visual experience and a very low level of non-visual experience. Certain maps, such as that depicting an emergency escape route from a building, will need to be very intuitive for this person to use and could possibly draw upon visual metaphors to present information clearly.

Person E represents a blindfolded participant in an experimental study. Like the person lost in smoke, this individual's source of impairment is external and temporary, but still quite challenging. This person will have a strong visual background and little familiarity with non-visual access technologies. Yet over the course of many participant sessions, he or she may become much more accustomed to simulated vision impairment and non-visual map use (illustrated by E').

The relative positions of D and E within the cube easily distinguishes the blindfolded subject often used in experimental tests from those with genuine vision impairment. It is important to recognize that while observations made during experimental sessions may be valid with regard to the functional utility of a prototype non-visual map, other factors such as personal comfort and social acceptance of new technologies may be dramatically different for those whose vision loss is permanent (Shinohara and Tenenberg 2009).

As a final caveat, the choice to use participants with simulated vision impairment for the demonstrative exercises documented in chapter 6 must be addressed. The use of simulated vision impairment, via blindfold, for participant research in this investigation is meant to reflect a condition of recent (adventitious) abrupt and complete vision loss. When participant research is performed, participants are assumed to have reasonably equivalent tactile facility and map skills. While research findings and accounts of blindness may not be universally applicable across the entire domain of visual impairment, some degree of overlap and extrapolation of findings can be expected. Furthermore, since it is noted that congenitally blind people generally outperform sighted people in tasks involving non-visual image perception (Heller 2002), blindfolded study participants can provide a general minimum baseline for expected task achievement.

Similarly, developmental considerations of users will not be addressed. For example, Aldrich (1993) notes from Heller's (1991) research that "processing information obtained through a series of touches places a greater demand on memory than processing visual information. Therefore it is reasonable to expect that tactile graphicacy in blind children may develop later than visual graphicacy in sighted children." (p. 284) Sensitivity to the differences between different personal circumstances must be cultivated as an awareness of the limitations in this investigation. Above all, an emphasis in this field of research must be cultivated that the experiences of blind and visually impaired individuals occur beyond laboratory walls.

2 Eras in Non-Visual Cartography

2.1 Introduction

Non-visual cartography is a discipline in which success and progress are ostensibly defined by productive output and innovation. Usable maps and geographic reference sources are required by non-sighted people and success will not ultimately have been achieved until products are devised to meet their needs. For this reason, the utility and capacities of our most recent mapping technologies and techniques are scrutinized as indicators of progress in this field. Areas where these maps are found to be lacking dictate where subsequent research should focus. Yet fixing a map that cannot meet its users' needs is not always as simple as revising the map itself. Often the underlying ideology or rationale that produced it is also incomplete or faulty and must be revisited first.

In Crampton's (2006) introduction to critical inquiry in mapping, cartography and GIS, he claims that "it is not so much the specific technology that should concern us, but rather the 'mapping tradition' that exists in any given moment. (p.12)" Mapping traditions are sets of principles, behaviours and beliefs that temper what, how and why certain types of research occur. These traditions help cartographers define and share their visions of research success as well as a common modus operandi for achieving them. The evolution of cartographic traditions cannot be explained using a narrative of unified linear progress wherein one school of thought replaces another. Cartography is a very plural discipline comprised of many overlapping traditions or concurrent modes of mapping practice (Dodge, Perkins and and Kitchin 2009), each of which provides a unique milieu for progress. The core principles of each mode push research and development in a certain direction and, accordingly, "every cartographic mode gives rise to its own kind of map artefact" (p.221).

To chart the course of an investigative journey, one must first become familiar with landscape that will be traversed. As this thesis is intended to be an exposition of unexplored territories on the research horizons of non-visual cartography, the larger domain, heritage and contextual surroundings of cartographic practice and scholarship must be recognized. Building an awareness of the modes of mapping practice that generate particular types of non-visual maps, as well as the lingering traditions currently at play in cartography and its non-visual sub-discipline will provide an important retrospective from which to orient further research.

Paradigmatic elements established along previous research paths may act as landmarks when navigating towards new research destinations. Once identified, paradigms from former eras in cartography that have been carried forward into current non-visual research will also be examined in the following discussion as a means of deconstructing certain troublesome issues from their roots.

The aim of this chapter is, therefore, to support the first objective of this thesis by critically evaluating the guiding assumptions established in this field and the influence these assumptions have held on efforts to improve maps for non-sighted people. Harris and Harrower (2006) suggest that we must debate and refine both cartography's theoretical and practical toolkits. Chapter two provides a theoretical preface to the more technology focused literature review of practical mapping research provided in chapter three. In doing so, it will serve to set the stage for this investigation by positioning preceding cartographic research in a broader theoretical context and then sighting new investigative possibilities that remain to be explored.

The full history of cartography is complex and it is not my intention to chronicle its complete evolution, as many other authors already provide comprehensive reviews[5]. However, many research traditions and modes of mapping practice active in non-visual cartography today have their roots in these former eras of cartographic history, so some re-examination is necessary. A timeline of eras in cartographic evolution is provided in Figure 2.1.

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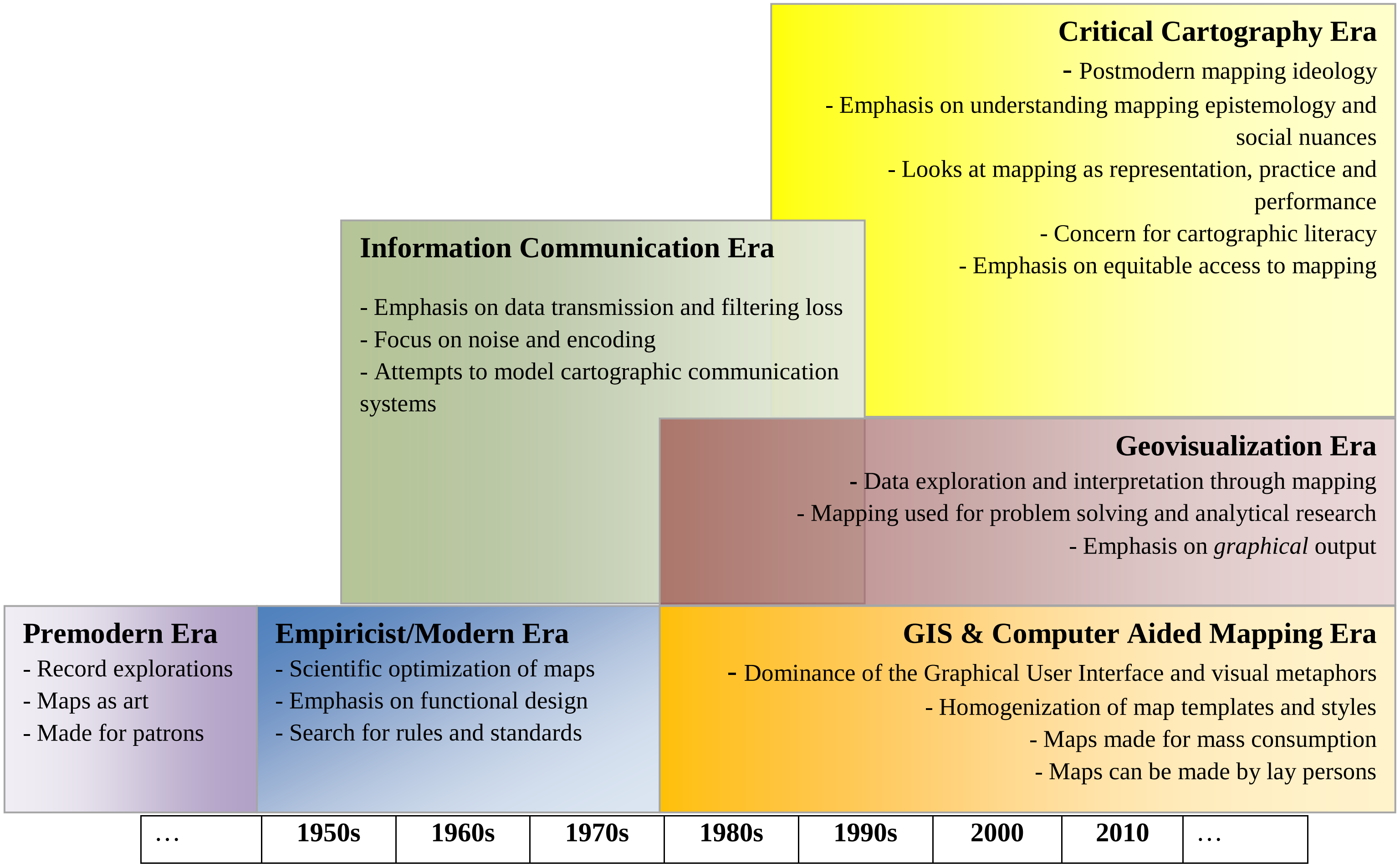
[5] Edney, M. 2007a. Recent Trends in the History of Cartography: A Selective, Annotated Bibliography to the English Language Literature. In *Coordinates*. American Library Association, Harley, J. B. & D. Woodward. 1987. *The History of Cartography*. Chicago: University of Chicago Press, Sluter, R. S. J. (2001) New Theoretical Research Trends in Cartography. *Revsta Brasileira de Cartografia,* 53**,** 29-37, Virrantaus, K., D. Fairbairn & M.-J. Kraak (2009) ICA Research Agenda on Cartography and Geographic Information Science. *Cartographica: The International Journal for Geographic Information and Geovisualization,* 44**,** 45-55, MacEacheran, A. 1995. *How Maps Work: Representation, Visualization & Design*. New York: The Guildford Press, Ramirez, J. R. 2001. Theoretical Cartography. Ohio State University Center for Mapping, Coppock, J. T. & D. W. Rhind. 1991. The History of GIS. In *Geographic Information Systems and Science,* eds. P. Longley, M. Goodchilde, D. McGuire & D. Rhind. Wiley.



Critical Cartography Era
- Postmodern mapping ideology
- Emphasis on understanding mapping epistemology and social nuances
- Looks at mapping as representation, practice and performance
- Concern for cartographic literacy
- Emphasis on equitable access to mapping

Information Communication Era
- Emphasis on data transmission and filtering loss
- Focus on noise and encoding
- Attempts to model cartographic communication systems

Geovisualization Era
- Data exploration and interpretation through mapping
- Mapping used for problem solving and analytical research
- Emphasis on *graphical* output

Premodern Era
- Record explorations
- Maps as art
- Made for patrons

Empiricist/Modern Era
- Scientific optimization of maps
- Emphasis on functional design
- Search for rules and standards

GIS & Computer Aided Mapping Era
- Dominance of the Graphical User Interface and visual metaphors
- Homogenization of map templates and styles
- Maps made for mass consumption
- Maps can be made by lay persons

Figure 2.1 Recent eras in cartographic history

In cartography’s early history, those who could produce maps for others were considered expert craftsmen. From this era a paradigm of cartographic authority and a number of essential presumptions about representing space where established. Prior to the second world war, map making was considered more of an art or trade than a science (Sluter 2001). However, from the 1950s through the 1970s cartographer Arthur Robinson’s provisions for a wholly scientific approach to western cartography changed this perspective. In this era we begin to see how certain empirical approaches for modern scientific research became entrenched in non-visual cartographic inquiry. Between the 1970s and mid 1990s a perspective promoting information communication research, the study of communication via maps (Robinson and Petchenik 1977, Ramirez 2001, Board 1972, Koláčcný 1977), was prevalent. In this era an abiding yet myopic concern for semiotic clarity and noise reduction in mapping was established.

While interest in some aspects of information communication research still remains, potent new modes of mapping practice introduced in the 1980s, 1990s and 2000s now overlap and interact to create the current cartographic milieu. The introduction of personal computers and graphical operating systems in the 1980s prompted a revolution in how maps were produced and published. Unfortunately, the GUI that has become ubiquitous in computing and GIS does not serve non-sighted users needs. Furthermore, through this revolution, formulaic processes of commoditisation and homogenization have created new expectations about the nature of maps that are also at odds with non-sighted user’s needs and lived experiences.

Proponents of computer aided cartographic visualization techniques produced in the 1990s provided a departure from the view that maps are simply tools for information communication. These scholars demonstrated that mapping can also be used to discover and depict previously unknown patterns in spatial information. In this era of Geovisualization cartography we begin to see an even heavier emphasis on visual primacy and pictorial modes of representation. Additionally, the solidification of many current forms of human computer interaction and digital map rendering that presently impede non-visual map use took place in this era. Finally, the critical cartography era spanning from the late 1990s into the new millennium has exposed many new perspectives that challenge maps roles as information constructs. This era identifies a variety of conceptual alternatives in the cartographic domain and provides new interpretations of map use and map authorship that stand to benefit non-sighted and sighted map users alike.

2.2 Premodern Cartography: Maps as Privileged Documents

The general impetus for map making is to create a document that records descriptive spatial observations and suppositions about a physical or social landscape (Kbanakubo 1993). The particles of representative content that fill a map intimate what has been or could be observed at a particular location. If desired, a map can then be used to revisit prior observations, or, alternatively, to spread or share ideas about spaces and places with others so they may vicariously learn about an unvisited environment. For this reason, maps have long been used to dispel what John Kirtland Wright called terrae incognitae (Keighren 2005). This term refers to "areas of the earth for which we have no firsthand experience and for which our knowledge and understanding is based upon the reports of 'geographically privileged persons' complemented and augmented by our own imaginations. (p. 549)"

The traditional map-maker/map-patron relationship has a long and enduring foundation. Throughout history until the advent of **remote sensing** technologies, knowledge about our world has been collected through a chain of explorers and cartographers whose firsthand experience gathering or depicting spatial information has made them geographically privileged persons to the greater populace. Ptolomy provided his *Geographia* to the people of Rome by compiling reports from soldiers sent to expand and secure their empire. Geographic insight in the age of exploration was facilitated by maritime explorers (e.g. Sir Francis Drake, Christopher Columbus, Captain James Cook, etc…) and educated courtesan cartographers employed by royal families, religious nobility, and ruling governments (e.g. Nicholas Germanus, Diogo Ribeiro, Gerardus, etc…). Modern continental explorations such as the US Geological Survey, the Royal Ordinance survey and the Dominion Land Survey were performed by engineering and military corps on behalf of national governments in the 17th, 18th and 19th centuries. Indeed the few explorers to land on the moon in the late 1960s are perhaps the most geographically privileged persons yet as firsthand knowledge of that landscape remains exclusive to them still.

While non-sighted people are able to perceive terrestrial geography in ways other than sight, it has become a routine mode of mapping practice for visual explorers to describe geography on their behalf. This relationship consists of geographically privileged persons upon whose reports and records others should rely and the corresponding passive consumer of information. The establishment of a binary map-maker/map-patron relationship has created a tendency to make maps FOR non-sighted people on their behalf rather than building the resources non-sighted people need to independently access mapping making tools.

There is an underlying assumption inherent to this mode of mapping practice that maps must be seen as concrete statements about geography. In a world where visual experience dominates our observations, those that can rely upon their own sight to gather data and participate in cartographic activities become geographically privileged and can easily assume an undue position of authority relative to non-sighted people. The dangers of this elevation are twofold. First, cartographers may proceed without adequate sensitivity for their audiences' needs and transformed experiences of space (Golledge 1993). What may seem to be highly relevant map content to a sighted person may be irrelevant or unintelligible to a non-sighted person and vice versa. Moreover, this relationship usurps the map user's agency to determine how landscapes should be represented and places it in the hands of an external map maker. The process of mapping then becomes one of creating commissioned work rather than a collaborative or empowering process. In many ways, this mode of mapping practice contradicts the emancipatory mantra 'nothing about us without us' embraced by disability interest groups (Charlton 2004).

While the exclusion of non-sighted people from mapping activities has been a longstanding issue in non-visual cartography, modern technologies for automating information processing can provide unprecedented opportunities to empower and return agency to non-sighted people. Yet new opportunities will only be realized if they are actively sought and respecting the status quo of mapping assumptions often dissuades this. It may have originally been necessary to assume that maps must be produced *for* a patron but this is no longer the case. Research in this field need not concentrate only on making better maps for non-sighted people, it must be concerned with how to better integrate non-sighted people in the domain of mapping.

In the visual context, users of online mapping tools are empowered to build highly relevant custom maps using open ended tools and publicly available data collections. Many popular mapping products today are more like interactive portals for accessing information than collections of finished scenes (Cartwright 2002, Dodge et al. 2009). However, this is not generally the case for non-sighted map users who must still pick and chose from pre-prepared maps made for their benefit by others.

2.3 1950 – 1970: The Empiricist/Modernist Era in Cartography

The approaches used to formally study and devise non-visual map products today reflects a heritage of scientific inquiry rooted in an era of cartographic empiricism that held strong between the 1950s and 1970s. Edney (2007a) suggests that at the core of the empiricist paradigm is a belief that “the worth and quality of maps are determined by the quantity and quality of their content, and that maps are therefore properly evaluated in terms only of that content” (p. 10).

One scholar in particular who adhered to this belief, Arthur Robinson, has had a major impact on how both visual and non-visual cartographic research has been conducted. Robinson viewed the treatment of map design as a matter of artistic license in prior eras as a source of confusion (MacEacheran 1995). To prevent this confusion he suggested two alternatives: either completely standardize the map design process or study map functionality to create rules that formalize the cartographic method. Thus throughout his career and in several seminal publications he argued for an emphasis on ‘functional design’ to make maps more efficient and on the objective evaluation of map utility (MacEacheran 1995, Montello 2002). This approach encouraged the development of standards for effective and pragmatic map making and touted controlled scientific experimentation as the best method for improving map functionality (Perkins, 2009b).

Perkins notes that the types of issues that were central to Robinson’s concerns included how location, direction, and distance were best represented; how information to be included in a map was selected and groomed for publication; how best to symbolize data; how to combine symbols, and what types of maps best suited particular predefined purposes. In order to garner much desired credibility in academia, Robinson also emphasized the employment of psychological experimentation on map perception and cognition in order to inform map design heuristics (Montello 2002, Perkins 2009b).

The tendency to rely on empirical experimental methods remains strong in non-visual map research. In a review of relevant literature it is not difficult to find many examples of empirical research that are focused on the issues Perkins highlights in the non-visual context. A limited selection of such issues includes investigating individual map design variables (resolutions, line heights & widths, recognizable tactile patterns, exploration procedures, aural symbols, etc.) and isolated functional mechanisms (mental representations of space, psychological perception of discernable map features, cognitive data interpretation, etc). However, non-visual cartography is still at a stage of research where a more holistic approach to inquiry is necessary to address broader epistemological questions, i.e. how do we use maps to achieve spatial understanding?

While the empiricist tradition provides a variety of very direct, hands on approaches to problem solving it does not deal easily with underlying ontological issues. Indeed, the identification of the most fundamental or critical issues to be addressed is not a given in empirical investigations. As such, many research efforts, though valuable, have not expanded their scope to sufficiently encompass the complete nature of the problems at hand. Research that addresses the variables within a problem that lend themselves most easily to empirical testing and statistical analysis may inadvertently place the cart before the proverbial horse. These investigations jump directly to matters of particularly conspicuous obstacles without first developing a sufficiently integrated premise as a research foundation. In an analogous example, it would be equally unproductive to focus on testing the properties of metals to be used to construct a better airplane wing without first achieving an understanding of the fundamental principles of lift and aerodynamics. Likewise, before testing map design variables for non-visual representation takes place an understanding of the operation and use of maps in building spatial knowledge by non-sighted people must be achieved.

2.4 1970 - 1995: Metacartography and the Information Communication Era in Cartography

Maps are meant to describe and communicate information about the spatial world. That is to say that they enable one or more people to acquire information about a geographic area from what is already known by another person. Investigating how the outcome of information dissemination via maps is achieved was the subject of much research from the 1970s through the mid 1990s.

Arthur Robinson's influence extends into this era of cartography's recent history. His publication of "The Look of Maps: An Examination of Cartographic Design"(1952)[6] opened the door for the map communication school of thought in cartography. Later works, such as "The Map as a Communication System" (Robinson and Petchenik 1977), "Cartographic Information – A fundamental concept and term in modern cartography" (Koláčcný 1977), "Cartographic Communication" (Board 1972), and "Cartographic Communication and Geographic Understanding" (Guelke 1976) firmly established this as a prominent mode of research. Studies in this area build upon theory provided by Bell Telecommunications researchers Claude Shannon and Warren Weaver, whose work led to the first model for information communication (Robinson and Petchenik 1977). Their model has since become known as the Shannon-Weaver communication model (Figure 2.2). This model was then revised in various ways and adapted for cartographic contexts. (Figure 2.3, Figure 2.4, and Figure 2.5)

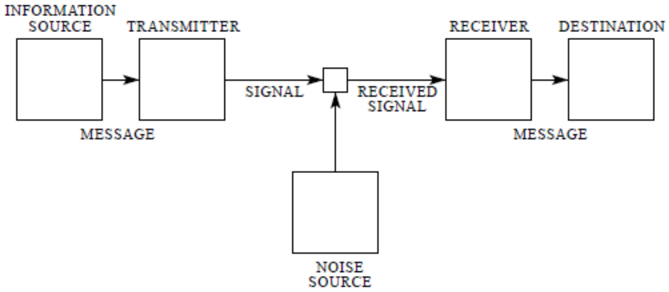


Figure 2.2 A schematic diagram of a general communication system illustrating the transmission of a data signal from an information source to a recipient (Shannon and Weaver 1949).

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[6] Later revised and republished in Robinson and Barbera Petchenik's anthology of essays *The Nature of MapsRobinson, A. H. & B. B. Petchenik. 1976. The nature of maps : essays toward understanding maps and mapping. Chicago: University of Chicago Press.*

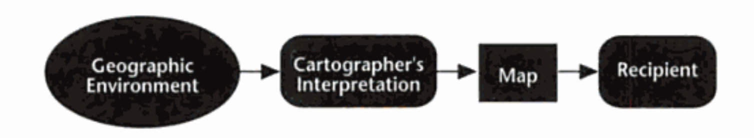

Figure 2.3 A schematic depiction of cartography as a process of information communication. (MacEacheran 1995)

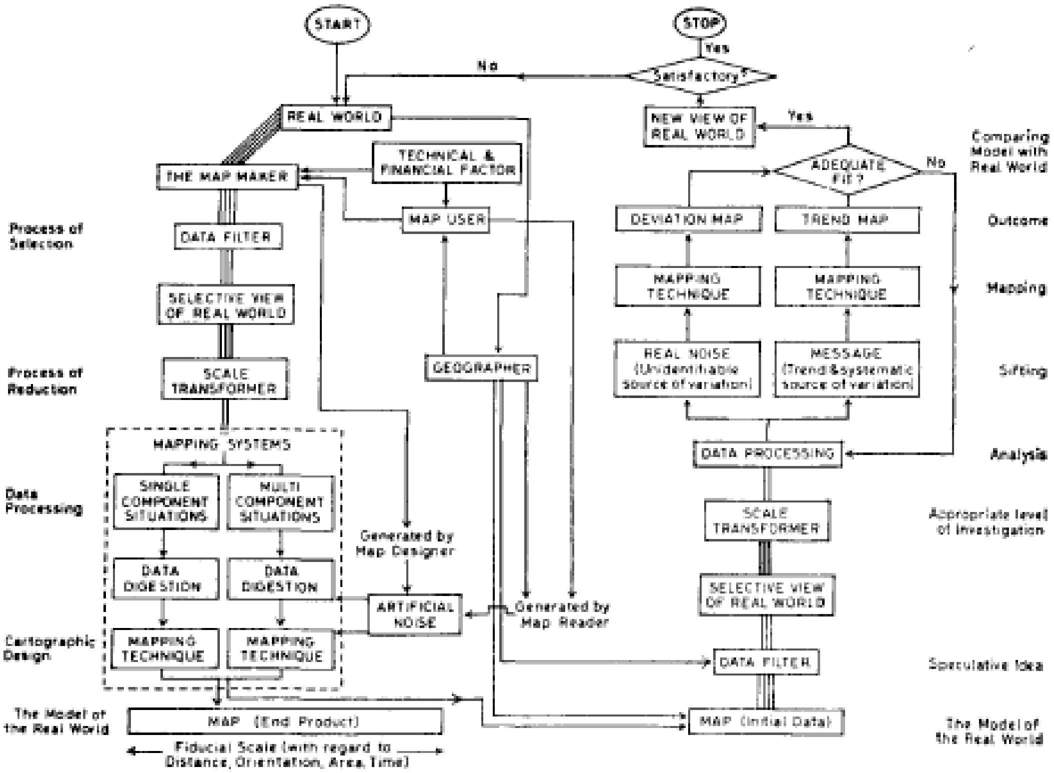

Figure 2.4 Board's (1972) Model of Cartographic Communication

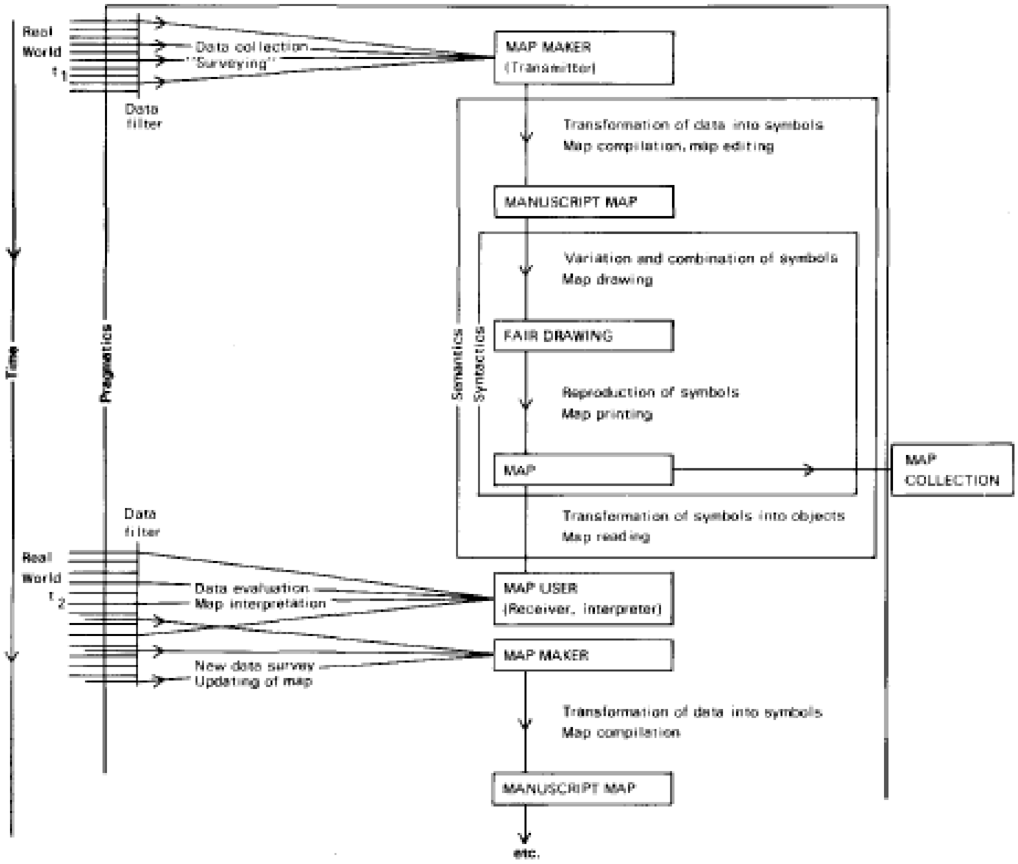

Figure 2.5 Freitag's Schematic Model of Map Communication (Board 1972)

The following excerpt written by Sluter (2001) provides a clear description of the information communication approach:

> First, a phenomenon that is to be studied (such as soil texture, the distribution of tree species in a forest, or human population density) is sampled and a data set is assembled. Then the mapmaker interprets this data set based on various classification and/or interpolation schemes. Employing this analysis, the cartographer then decides on a design for the map, which is then produced employing best-practice design principles in an attempt to create a map which provides an "optimal" representation of the data (and hopefully of the nature of the phenomenon under study). In the last step of this process, the user interprets the phenomenon based upon the cartographer's ability to correctly communicate his or her ideas.
>
> However, there is "noise" in each step of this process. First, the data are but a sample of the reality of the phenomenon under study, and may not be entirely representative of it. Second, the cartographer may misinterpret the data and thus provide an inaccurate view of the phenomenon. Third, the map design may not communicate the cartographer's interpretation fully or accurately. Lastly, the user

> may not understand the map completely. So, the aim of research in this paradigm was to "reduce the noise level" and to create the one map which optimally represents the phenomenon and successfully communicates this information to the map user. (p. 2)

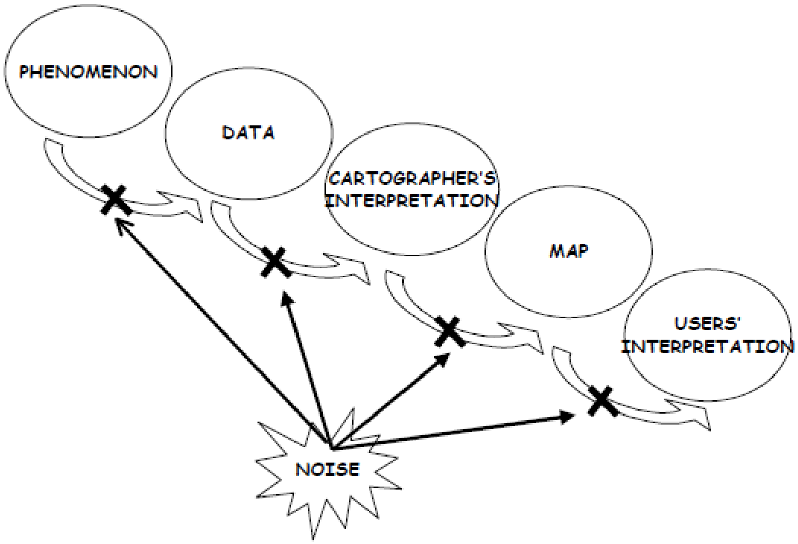

Figure 2.6 A depiction of noise in all steps of the cartographic communication process. (Sluter 2001)

At the core of this school of thought is an assumption that the information presented within a map is, in fact, *explicit knowledge* that is concrete, self-evident and immediately recognized and internalized. This suggests that all that must be done to acquire the information a map provides, given that consistent and concrete symbols are defined and used, is to simply perceive the represented data encoded in a map and commence with the mental interpretations needed to sort and utilize the collected data. Noise that prevents the clear transmission of information, by muddling or filtering the intended message, must be identified and removed to ensure that information transmission is successful (Figure 2.6). To explain, Alan MacEacheran (1995) recalls that

> Treating cartography as a formal communication system implies that we can improve map communication if we can reduce the filtering loss of information at various points in the system… Most efforts to study cartographic communication have been directed to the middle stages of the system: the cartographer’s transformation of selected information into the map and the initial extraction of map information by the user. (p. 5)

While this comment was posed in regard to cartography as a whole fifteen years earlier, it remains equally applicable to non-visual cartography today: most efforts to study non-visual cartography remain directed at the middle stages of the system. Examples of typical manifestations of this 'filtering loss' paradigm include the testing and refinement of multi-modal data encoding strategies (Power 2008), attempts to perfect and standardize **symbology** design (Challis 2000, Jehoel 2008), studies that seek to optimize the efficacy of exploration strategies for tactile graphics (Berla 1981), and assessments of stimulus perception and cognition (Klatzky et al. 1993a, Millar 1994). Although new modes of mapping practice have reinterpreted the role of maps in geographic discourse, finding effective data encoding and presentation strategies remains a fundamental obstacle to be addressed. The experiences gained from the use of basic tactile map formats developed out of sheer necessity over the past 50 years have helped identify many issues to be considered with respect to the utility of non-visual maps, their users, and geographic communication.

2.5 1980s Onward: The Digital Mapping Era

The advent of new means of map production has always provided catalysts for change in cartography. By enabling the identical reproduction of manuscript maps the printing press established the first roots for mass production in mapping (Tatham 2003). The digital revolution enabled by the introduction of reasonably powerful and affordable personal computers through the 1980s prompted another change in cartography driven by new means for mass map production. Computers allowed cartographers to quickly and easily create and edit maps and then publish them en masse to a wide-spread audience. As a result, following the mid-1980s more people regularly encountered and accessed maps than ever before, especially online using computer technologies (Peterson 1997). Furthermore, map creation and map use has become an integral component of more and more specialized professional activities (Andrienko, Andrienko and Voss 2002). However, the evolution of computing technologies has had a contradictory impact on non-sighted users.

Two central issues have resulted from the mode of mapping practice enabled by computers in this era. The first is that computer systems used for mapping and map access have almost exclusively been developed around GUIs, visual metaphors and optic displays (Coulson 1991). While the introduction of accessibility technologies, such as refreshable Braile displays and text to speech synthesizers, have proven that computers can indeed create opportunities for non-sighted people to join previously inaccessible activities. The advent and dominance of GUIs in computing have impeded these opportunities (Bellik and Burger 1995). As a result, non-sighted computer users may experience significant difficulty operating GISs developed around visual premises even if accessibility accommodations are provided.

The second issue is that computer aided mapping has served to entrench a particular orthodox template for mapping that is biased towards visual perception and does not reflect the lived experiences of non-sighted people. The task of innovating new non-visual maps is thus constrained by a very narrow archetypal model that defines the expected character and form of maps. A great deal of conceptual homogenization and stylistic standardization has taken place in cartography as a result of the bias toward visual perception.

Computers and their component hardware devices and software play many different roles in mapping activities. Beaudoin-Lafon (2004) notes three particular assistive roles for personal computers. They may serve as a medium that both enables the presentation of digitized information and facilitates interpersonal communication online, as a tool that expands and enhances a user’s abilities, or as a partner that can carry out delegated tasks for the user. For non-sighted people, computers performing these roles can provide tremendous value. However, in order to realize this value computer systems must be designed with a user’s sensory capacities and lived experiences in mind.

The way a computer engages its user, both physically and interactively is critical. Computer systems are sensory motor systems wherein “the user acts on the system, which in turn generates output perceived by the user” (Beaudouin-Lafon 2004)) (p.19). From their inception, GISs have traditionally been designed by and for sighted operators. GUIs that use optic displays, visual information organization schemas, pictorial symbols and ornamentation have evolved accordingly to dominate human-computer interactions. Unfortunately, none of these elements are suitable for non-sighted users who may not fully perceive optical stimuli, be able to navigate visually organized information, or readily relate to common symbolic graphics and iconography.

GUIs have often turned to visual metaphors to populate onscreen output. Kuhn (1991) contends that GUI metaphors are deficient, insofar as they depend on shared lived experiences. For instance the pervasive Windows, Icons, Menus, and Pointers [WIMP] schema popularized by Apple Computer Systems in 1984 relies on viewing content as if looking through a window, identifying iconic pictures and symbols, selecting items as if reading from a written restaurant menu, or point and clicking visual targets (Berliss 1993). Visual metaphors are also heavily used in GIS (Figure 2.7). The metaphorical action of zooming in or out on a map scene is akin to viewing samples through a magnifying glass or microscope and has no non-visual alternative (e.g. swelling and deflating). Likewise, information queries are often performed using a crosshair icon, as if looking through the sights of a gunscope or binoculars. Measurement tasks are often represented using a straight ruler. The dragging hand metaphor used to change the visible area of a map is akin to the use of a light table or microfiche device (Cartwright et al. 2001).

Figure 2.7 Examples of visual metaphors commonly used in GISs. Stock tags (Label), binoculars (Find), rulers (Measure), magnifying glasses (Zoom and/or Select), an eyeball (Change view), letters of the alphabet (Text Input), and computer screens (Resolution). (ESRI 2008)

Rather than perpetuating visual metaphors in non-visual circumstances, new non-visual metaphors and interaction alternatives must be formalized. Two differing approaches have generally been employed to reach this goal. This first approach attempts to create assistive mechanisms based on **universal design** premises that retrofit and enrich existing GIS systems so they can be used by non-sighted people. In essence this approach promotes redundancy in computer systems through the development of multimodal interfaces (Kortum 2008), wherein two or more interface elements, such as a GUI and/or speech recognition system, can be used to achieve the same task. The second approach attempts to design separate computer systems that are intended solely for use by non-sighted people with the hopes of optimizing their experience. To maximize the value of human computer interactions, Beaudouin-Lafon (2004) suggests that research must, above all, focus on designing interactions rather than designing interfaces. While both approaches have their own merit and potential for success, other sociocultural obstacles have also impeded the development of viable non-visual geographic information systems.

The revolution that boosted map output using computers also established a sense of authority and orthodoxy in cartography; mostly in terms of how maps were designed, but also in terms of how spaces and places are perceived and represented. Besides being faster and less labour intensive than drawing maps by hand, computers are now used to create geographic representations because they are seen as the best tools for the job. In addition to personal computer robustness and flexibility, the continual upgrade and revision process for mapping software reinforces an idea that the tools for mapping that are newest are also the best and most accurate or powerful. And while computers may be procedurally exact and less prone to error, maps produced on computers always reflect human choices, perspectives, values and biases (Monmonier 1991).

As Montello (2002) asserts, map design is in many ways a form of mind design. Our internalized conceptualizations and interpretations of space and geography are reflected in the ways we create representations of spatial information. Dodge, Perkins and Kitchin (2009) state that computers "en frame and exclude, working as mediating windows on the world. (p. 222)" A critical evaluation of this tendency for mediation can be very instructive. Maps are now highly recognizable artefacts in contemporary society. We encounter them daily in a wide range of contexts. The ability to recognize a map is developed through countless encounters. Each encounter contributes to an impression that defines how a map should or should not appear based on all previous examples. Thus, when new maps are made they generally conform to this impression so as to seem correct in juxtaposition with other recognized maps. This is a virtuous cycle since the more we encounter certain map tropes the more they inform our spatial awareness and correspondingly the more we reify that awareness in subsequent map making efforts**.** In essence, the publishing scope enabled by computer aided mapping has facilitated a common and expected normative standard that defines what a map is and should look like.

The development of Geographic information Systems and computer assisted map making coincided with a push for unprecedented levels of information commoditization in the late 20th century. Maps were produced for sale in styles and designs that would appeal to the largest and most profitable market segments. Examples include road maps for the driving public, topographic maps for farmers and industrial developers, land use maps for planners and so on. These products were more likely than not to be produced as flat images depicting an overhead view of the earth's surface. This form of representation mainly involves tracing the outline of what could be seen from above for topographic reference, often using aerial and satellite photography collections that were also vastly enhanced by computer technologies, (Cartwright 2002). Indeed, many interactive maps services like Mapquest, Google Earth, and OpenStreetMaps now allow **georeferenced** map content to be seamlessly superimposed directly over aerial photography (Figure 2.8). In this way, maps made with computers have become imbued with an essence of correctness and verisimilitude because they seem to reflect ‘objective’ observations from photographic sources. This style’s ubiquity and familiarity has also made it the default template for non-visual map concepts (Kent 2008). Unfortunately, preconceived notions and norms about the proper character of maps prevent unorthodox map types from gaining traction even though many other non-Euclidean perspectives of the earth have been used throughout premodern history (Figure 2.9).

Figure 2.8 Georeferenced cartographic data and photographic imagery

Figure 2.9 Ammassalik Wooden Maps depicting the coast of greenland Source: (Bagrow and Skelton 2009)

Geographic representations constructed for non-sighted people tend to embody visual map designs of spatial data transposed into alternative formats, such as Braille and tactile maps (Rahimi and Eulenberg 1974). For instance, instead of printing a polyline figure depicting a road network in ink on paper, raised lines are embossed or etched into hard materials to create tactile relief patterns.

Unorthodox constructions of spatial information that may benefit non-sighted people are often avoided if they conflict with traditional visual map archetypes. Alternative examples of spatial information sharing strategies (song, dance, sculpture, games, etc.) suggest that many alternatives have not been given enough merit. Practicalities aside, this would be a very different investigation if relief globes or models, carved sculptures, woven textiles, song and dance, or dioramas were accepted as the natural embodiment of mapped spatial information, rather than images that are printed on paper or displayed on screen. Instead of becoming integral modes of geographic dissemination, maps that represent information through atypical means have been unable to overcome a strong visual bias in cartography and have instead been shunted to a separate stream of practice (Perkins 2002).

Biases in cartography are often rooted in our primary means of perception. A mismatch between a map's representation and a map user's perspective is likely if biased assumptions are made about what information is most useful and how it is best presented. Studies performed by Klatzky, Lederman and Reed (1987) illustrate this concept. When asked to explore a selection of varied objects and choose one that best matched a provided sample, participants identifying objects visually tended to find pairs with corresponding geometric properties like size and shape. Non sighted participants, however, tended to select pairs with matching material properties, like surface texture or material compliance. The qualities considered most salient to each participant's choice were directly related to their perceptual modalities and exploratory preferences.

Not surprisingly, maps that are designed on computers and derived from photographic imagery may be as foreign to non-sighted people as the photographs themselves. Similarly, the web of a road network is frequently included as a ubiquitous system of reference in modern maps. Its use is so common that it has even been criticised in visual contexts for creating maps of 'blandscapes' that are devoid of meaningful character (Kent 2008). Understandably, the 'streets-as-seen-from-above' style is often very disengaging for non-sighted people who cannot drive a car on these roads. Distinguishing where the values, perspectives and biases of sighted and non-sighted people diverge is tremendously important. Identifying agreeable map structures and meaningful content that will resonate with non-sighted map users' lived experiences will be an important next step to transcend traditional map offerings.

2.6 1990s Onward: The Geovisualization Era in Cartography

The proliferation and refinement of personal computers following the 1980s dramatically enhanced the power and capacity of cartographic activities. Much of the effort devoted to cartographic progress has, in this light, been intended to establish better and more correct map making techniques with which to objectively communicate spatial information and delineate geographic reality. Yet this is an incomplete approach to spatial inquiry, as information communication perspectives only recognize representative processes and do not allow for analytical investigations of spatial phenomena through mapping (MacEacheran 1995).

In the era of Geovisualization cartography brought about in the 1990s, a more analytical and exploratory form of mapping was introduced to challenge the traditions and assumptions of the information communication era. The conceptualization of **geovisualization** first occurred in the late 1980s (MacEachren et al. 2004), but it was not until the mid 1990s that it became truly established as a recognized facet of professional cartography. During this time MacEachren published his seminal text “How Maps Work”(1995) and the ICA Commission on visualization and Virtual Environments was established (MacEachren and Kraak 1997).

Geovisualization espouses that there are many different ways to represent abstract spatial phenomena and there is no optimal map to be attained through empirical investigation. This approach instead leverages mapping both for the presentation of known spatial information as well as for the discovery and analysis of unknown patterns in spatial data (MacEachren et al. 2004).

Beyond its impact on the visual character of maps, Geovisualization cartography has cultivated a new perspective on the interplay between maps, users and cartographic contexts (|Figure 2.10). Whereas the information communication era provided a linear model in which map percipients passively consumed spatial information, the Geovisualization era provides a much more dynamic interaction model.

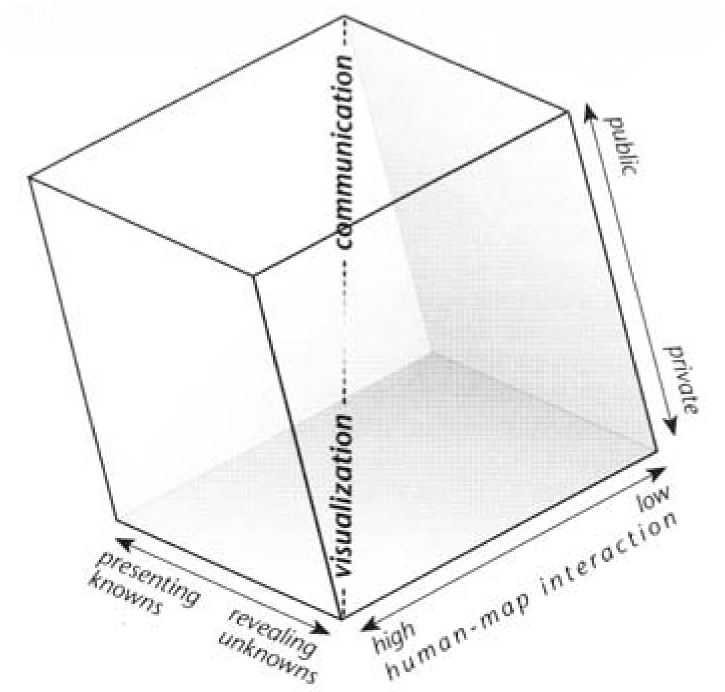

Figure 2.10 MacEachran's (1995) conceptual model of geovisualization cartography.

The advent of Geovisualization cartography has had a two-fold impact on research in non-visual cartography: a dominating emphasis on visual representation and an interest in the process of knowledge creation through mapping. As its name implies, Geovisualization promotes a perspective on mapping that seeks the production of new visual and pictorial representations of spatial information. Despite purported interest in creating unorthodox depictions that give new life to spatial data, geovisualziations tend to create rich visual abstractions that narrowly filter out non-visual information. Ironically, Kraak (2003) stresses that geovisualization should "entail removing mental roadblocks and taking some distance from the discipline in order to reduce the effects of traditional constraints" (p. 392) and thereby "chose alternate methods of mapping." Yet the end result is nevertheless expected to be "new, fresh and creative *graphics* [emphasis added]". This perspective not only inhibits access to cartographic materials for non-sighted individuals, it also excises considerations of alternative sensory experiences from the cartographic milieu.

Cartwright et al. (2001) note that creating interfaces that ensure equitable ease of access and use is integral to ensure the success of geovisualization. Unfortunately, rather than pushing the boundaries of disability friendly Geovisualization interfaces, universal access initiatives have tended to focus more on creating socially equitable interfaces that enable map access in both public and private realms by expert and casual users alike. An agenda for the creation of multi-sensory Geovisualizations has been promoted throughout this era (Oviatt 1996), but the output of projects in this vein are centered on enriching visual depictions with additional sensory modalities more than creating renderings of geographic information that are not primarily visual. As such, efforts outside of Geovisualization circles intended to create GIS interfaces that are accessible to non-sighted people have not yet escaped in the information communication mentality and its traditional assumptions.

2.7 2000 Onward: The Era of Critical Cartography

An emerging movement steeped in the ideals of **postmodernism** has recently prompted a reassessment of the nature of cartography. The birth of this era took place through the 1990s and has gathered momentum in the new millennium. Critical cartography, as the new paradigm of this era is now labelled, places a focus on the ontology of maps as systematic accounts of spatial reality (Crampton 2009, Howe 2011, Perkins 2009b, Schuurman 2006). The critical cartography movement was prompted by dissatisfaction with certain accounts of spatial reality, and the implications thereof, provided by particular maps and methods of mapping.

The fundamental premises of critical inquiry have already been introduced, to a degree, in chapter one. The intention of critical cartographic inquiry is not to find a single new approach to replace what exists in the cartographic domain. Rather, it suggests that a more integrated and comprehensive approach must be developed to fill in what is lacking. Crampton and Krygier (2006) have, therefore, described critical cartography as a “one two punch of new mapping practice and theoretical critique. (p. 11)” However, this paradigm’s background and contributions have not yet been fully addressed in this investigation.

Schuurman (2006) asserts that three waves of critique in **GIScience** have passed since the era’s inception. The first wave of critique, from 1990 to 1994, took exception to the perceived difficulties incurred by positivistic and overly quantitative approaches to spatial analysis and visual representation. The second wave, from 1995 to 1998, broached concerns that Geographic Information Science/Systems mainly served the interests of powerful cartographic elite, such as large corporations and government institutions who could afford GIS infrastructure, rather than disenfranchised and marginalized groups. The third wave, following the late 1990s, shed much of the antagonistic tone of critique displayed in earlier years and instead employed critical inquiry to fertilize the growth of alternative conceptualizations of cartography and new modes of mapping practice. Novel concepts like public participation GIS, cartographic literacy, embedded power structures, map accessibility, and the affordance/performativity aspects of maps first became concerns during this time. This last and longest wave has certainly also been the most fruitful in terms of exposing new opportunities for progress in non-visual cartography.

The following discussion will detail how the critical cartography paradigm developed as well as what contributions it has made so far and stands to offer yet to visual and non-visual cartography. Where possible non-visual examples will be used to illustrate the concepts of critical cartography as a way of directly emphasizing how this paradigm stands to benefit non-sighted map users.

2.7.1 Theoretical Critique

The first seeds for theoretical critique in the critical cartography era were planted in the late 1980s. Historical geographer J. B. Harley began drawing upon philosophers outside the cartographic discipline in order to identify the shortcomings of the positivistic and autocratic tendencies he observed in GIScience and modernist cartography. Harley’s methodologies drew upon premises found in Kant's "The Critique of Pure Reason", as well as works by Derrida concerning deconstruction, and works by Foucault on power and knowledge. In "Deconstructing the Map" (1989), which is now recognized as a classic text in cartography (Cartographica 2007), Harley addresses the politics of cartographic knowledge and examines the grounds of the field's decision making traditions. He asserts that cartographers have created an “epistemological myth” that their methods reflect “the cumulative progress of an objective science always producing better delineations of reality (p.15)”. Harley’s argument posits that the interpretive act of map deconstruction serves three functions: it allows us to challenge the idea that cartographic practice represents the cumulative progress of an objective science; it redefines the historical importance of maps and modes of mapping practice; and it provides a turn of mind that allows history to take a fuller place in the study of maps and spatial knowledge systems .

Harley’s argument contends that the process of mapping consists of creating, rather than simply revealing, knowledge and information claims (Kitchin and Dodge 2007). The success of Harley's assertions and method for critique has since inspired many others to continue in this fashion to deconstruct and critically evaluate other traditions and concerns in cartography (Edney 2007a). Since Harley's death shortly after the publication of "Deconstructing the Map" (1989) a great deal of discussion has been provided concerning the ontology of maps by various scholars, including Jeremey Crampton, John Pickles, Denis Cosgrove, Martin Dodge, Matthew Edney, John Krygier, Chris Perkins, Denis Wood and Jon Fels (Kitchin 2008, Edney 2007b).

The notion of theoretical critique currently espoused by critical cartographers, detailed in section 1.2.1., does not entail a hunt for bad maps or fault. Rather, it entails seeking alternatives to existing modes of thought by cultivating a measure of vigilance and awareness of the limitations of common approaches (Harris and Harrower 2006). This allows cartographers to determine who is served and who is marginalized by certain modes of cartographic practice.

The dismissal of established theories is certainly not an unprecedented occurrence in cartography. As it has been shown in preceding sections, new schools of thought have often opposed and diverged from the tenets of preceding paradigms. However, critique in these instances was generally more passive than active and did not directly target established notions. Instead they posed new suppositions in juxtaposition to old assumptions in order to demonstrate opportunities for progress.

The technology fuelled evolution of geovisualization as a response to the inadequacies of information communication perspectives (Crampton and Krygier 2006) is one such instance of this passive juxtapositional form of critique. The Geovisualization paradigm did not actively position itself as an alternative to information communication, but rather surpassed it by pressing on towards inherent opportunities for progress. Interestingly, the critical cartographic school of thought both builds upon and opposes the concurrent geovisualization paradigm. Critical cartographers recognize and build upon notions established through geovisualization scholarship that maps have a capacity for knowledge construction. However, where the geovisualization paradigm suggests that maps can be used to divulge new claims about the spatial nature of the world, the critical cartography paradigm frames maps as catalysts for the creation of knowledge in the minds of individuals.

2.7.2 New Mapping Practice

Several new developments have been added to the body of cartographic concerns as a result of the new tradition of theoretical critique that is engaging this discipline. The search for alternatives to established ideas that is facilitated by theoretical critique has led to the discovery of many conceptual pairs (Del Casino and Hanna 2006). Examples taken from the extended list Perkins (2009b) provides in his study of philosophy and mapping, include representation and practice, production and consumption, text and context, cartography and cartographic literacy, among others. In identifying these pairs, new concerns are evoked for cartography as a whole and non-visual cartography alike.

The following section will delve into the nature of these new concerns about mapping. Instances where valuable new concepts have been introduced into the domain of visual cartography without having permeated the non-visual cartographic milieu will also be highlighted.

2.7.2.1 Representation and Practice:

In “Rethinking Maps” Kitchin and Dodge (2007) argue that cartography may be profitably conceived of as a processual phenomenon rather than a strictly representational science. They assert that while maps as individual objects are necessary components of geographic learning, in that they make spatial information available, the complete process of geographic learning encompasses much more than the representational rendering of landscapes on paper. They and other scholars assert that mapping is performative (Perkins 2009a), in that various practices and actions related to map production and consumption must be performed in order to realize the value of a map. For instance, many activities ranging from data collection to symbol selection to image composition must be carried out in order to create a map (Sluter 2001). Likewise, in order to utilize the information a map makes available, a number of subsequent practices must be performed. First, the information represented in a map must be perceived through sensory exploration. It may also be questioned to assess its accuracy and validity or measured to provide values for other calculations. The information a map presents may also be moderated and negotiated in many other ways: it may be annotated, organized, highlighted, copied, or linked.

Because map performance is not static or prescribed and varies from person to person, maps do not emerge in the same way for all individuals (Kitchin 2008). Maps always exist within a larger context and their meaning is established through “a mix of creative, reflexive, playful, affective and habitual practices (p. 214).” Corner (1999) argues that cartographic theory has been hampered by a “preoccupation to view maps in terms of what they represent and mean, rather than what they do (p. 217).” As a means of departure from this preoccupation, he develops an understanding of maps as unfolding potential, as conduits of possibilities, and sites of imagination and action in the world. He suggests that the function of maps is, therefore, not to depict but to enable. Rather than representing ideas about geography mapping affects personal actualization. Mapping involves processes of “gathering, working, reworking, assembling, relating, sifting, speculating and so on that allow certain sets of possibilities to become actual (p.228).” The traditional assumption that these tasks must be carried out by a mapmaker on behalf of a map user simply entrenches an unnecessary relationship of co-dependency. Furthermore, conceptual and technically-driven developments in the way maps are made available digitally via computer to sighted users have “begun to fundamentally transmute the role of the map from a finished product to a *situation* where the map is displayed within a visual toolbox to be used interactively” (p. 8)(Kitchin et al. 2009). To continue to emphasize the production of finished map products, or the development of tools to access finished map products, as the end-goal for non-visual research would not fully achieve an equitable level of access to maps and geographic information sources.

For those who recognize the performative nature of mapping, understanding the affordance value of maps is paramount. Affordances are the actionable properties of an item (Meng 2008). They define what achievements a map may facilitate, for whom and how. A map that affords the perception of spatial information via visual inspection allows those with functional sight to glean its contents. Alternatively, a map that also affords the perception of spatial information via aural or tactile means allows those who do not have sight but are otherwise sensorial unimpaired to glean its contents. Beaudoin Laffon (2004) asserts that because we have not understood the value of affordances, attention has been overly allocated to the design of personal computer interfaces rather than the interactions they enable. As both visual and non-visual maps are now increasingly rendered using computer technologies exploring the value of affordances and interaction solutions is key.

2.7.2.2 Text and Context

Much of the momentum fuelling research in critical cartography is derived from the potential for social change that alternative conceptualizations of mapping can provide. Maps, in the critical cartography paradigm, are seen as expressions of power and embedded social visions. Where maps were previously viewed as concrete, objective and explicit delineations of geography, critical cartographers posit that maps are, in fact, sets of knowledge claims supported by social constructions of power and authority. In this sense, knowledge claims in maps do not record geographic reality but actually actively create it. Maps are said to have become both the provocateurs and the documentation of political struggle throughout history (ITCP 2006).

Much of the discourse of critical cartography is concerned with the notion of social politics and authority embedded in maps. Harley cast maps as social constructions and expressions of power. As such, the value of a map's text must be examined relative to the contexts in which it is created and/or consumed. If maps are knowledge claims supported by agents of power any person with recognized agency can make competing and equally powerful claims about the world.

The idea that maps express ontological and epistemological systems within which geographic reality is coded and categorized has garnered much attention in critical cartographic literature. Pickles (2004) posits that "instead of focusing on how we can map the subject, [we could] focus on the ways in which mapping and the cartographic gaze have coded subjects and created identities (p. 15)." In this light, maps enable the production of tropes for space, geography, place and territory by serving as seeds of data from which individuals may cultivate their own intimate knowledge and claims about space relevant to their own personal worldviews and lived experiences. Montello (2002) suggests that map design is mind design, for the mental input a map provides consequently affects the cognitive construction of geography the mind arrives at. How this cultivation of knowledge takes place is viewed as vital to critical cartographers and has prompted a new line of investigation towards cartographicacy (Aldrich et al. 2003).

Given that maps used by sighted and non-sighted people must necessarily differ in format, and for the sake of meaning should likely also differ in their spatial attributes, it is important to differentiate between sighted and non-sighted contexts. The term cognized environment, or **umwelt**, alternatively, is often used to describe the particular character of reality that is perceived by individual organisms according to their perceptual abilities and life contexts (i.e. sighted, non-sighted, etc). In his studies of communication and cybernetics, Roth (1999) demonstrated that, depending on their particular backgrounds and/or umwelts, individual students do not necessarily perceive and act in the same worlds shared by their colleagues and instructors.

2.7.2.3 Cartography and Cartographic Literacy

Throughout much of cartography's history, the ability to comprehend mapped information has been taken for granted or seen as a function of the communicative effectiveness of a particular map design. However, scholars in this era have suggested that meaning is derived not only from the quality of a map's construction, but also the wherewithal of its users. Aldrich et al. (2003) note that two faces of mapping must be recognized: cartography and cartographic literacy.

Graphic literacy, or graphicacy, as defined by Aldrich et al. refers to "the demonstrated ability to comprehend and produce graphics. (p. 284)" Cartographic literacy, or cartographicacy, therefore, refers to a demonstrated ability to comprehend and produce maps and geospatial imagery. It entails a set of reading and writing skills and intimate knowledge of a range of design and symbol conventions. Cartographicacy is a knowledge set that must be learned and is established through common consensus among a population of map users. This conceptualization plays on the dialectical representation/practice and production/consumption pairs to reaffirm the performative nature of mapping.

Graphicacy is often listed along with literacy and numeracy as a core component of basic education (Clifford and Valentine 2003, Matthews and Herbert 2008), but cartographic literacy is rarely included. Before cartographicacy was placed in the spotlight of cartographic inquiry, the development and teaching of map use and map comprehension skills was not readily considered. In educational contexts, classroom time is more often spent focusing on the subject of a map at the expense of teaching map use and comprehension skills. To wit, in her 2005 report to the International Cartographic Association on the Agenda 21 goals for child education in the twenty first century, Anderson (2005) states "Despite the fact that maps are a complex form of graphic expression, it would appear that, because maps are universal and interdisciplinary, there is the basic belief that in education concepts associated with maps and mapping require little attention. (p. 2)"

Like any tool, maps require a basic functional understanding in order to be used correctly. The teaching and practice of cartographicacy skills should be seen as a necessary component of geographic education and a valuable, though presently underprovided, component in school curricula. Furthermore, visual and non-visual cartographicacy skills, such as those used to comprehend visual and tactile maps, are thought to differ significantly. The critical cartography paradigm has made an effort to highlight the traditional absence of educational on map comprehension skills.

Particularly in non-visual contexts, methods for developing and teaching unfamiliar map reading and writing skills must be considered before mapping success can be expected. Besden (2009) provides an apt example of cartographicacy in non-visual circumstances in her discussion of orientation and mobility training for transit usage. As transit systems are heavily used for independant travel by non-sighted people, the ability to comprehend and use informational materials to plan journeys is critical. She notes that successful navigation using a tactile map requires the development of several cartographic literacy skills. These skills include indentifying locations of interest according to a variety of attributes (labels, location, symbol, etc.), following route paths and exploring how routes intersect with each other to form a network, estimating distances between points on a map, attending to cardinal directions, and mastering concepts like between, next to, near, before, after, inside of, outside of etc.. Each of these is a transferable skill that is neither tied to nor provided by any particular map. They can be used to comprehend and produce cartographic imagery at will.

2.7.2.4 Exclusion/Participation

The exclusion/participation binary pair relates to issues surrounding who is or is not able to make, access, use or share maps. Exclusion and participation issues emerge in two ways in the domain of mapping. Groups and individuals may be excluded from accessing the means of mapping or conditions of social exclusion may be reflected in the depicted content of maps. Cartographic specialists have been given societal licence to create representations of the world as they see fit with the expectation that the maps produced will be objective, inclusive accounts of geographic reality. Critical analyses of this tradition suggest that no such outcome is possible. Yet maps cannot be truly mimetic as they are always abstractions of reality bound to the cartographic gaze and intentions of their designers (Pickles 2004). As such, maps must be seen as political manifestations of social ideologies, cultural beliefs, and power structures.

Critique of the political nature of maps has identified many forms of cartographic social intervention. Maps delineate territories and social boundaries (Biggs 1999); they conceptualize identity by differentiating ourselves from others (Perkins 2009b); they differentiate enemies from allies and relay military orders (Zarycki 2001); they enable civic agency (Elwood 2009); they can be used as propaganda or as forms of grass roots resistance (Robinson 2007); and they can provide channels for self-expression (Kwan in Wilson and Poore 2009).

For groups such as the population of non-sighted people, the inability to participate in mapping activities has a wide range of social ramifications. Cultivating new participatory modes of mapping practice that encourage a more equitable cartographic domain should, therefore, be seen as a desirable alternative to existing instances of exclusionary practice and traditions of hegemony.

Fortunately, situations of exclusion are not static and many new opportunities for participation in mapping activities have emerged in this era. Most importantly, the advent of personal computers is changing the ways that people are now able to participate in mapping activities. As Crampton and Krygier (2006) note, the general business of map-making is passing out of the hands of experts. Elwood There is a shift in the politics of expertise in cartography (Elwood 2009).

As a result of the connectivity experienced in the new millennium, many new cartographic tools do more than simply provide access to maps – they provide individuals with opportunities to create maps that serve their own unique needs. Mapping can now be done by anyone with a home computer and access to the internet. For non-sighted individuals, this shift highlights the need for more universally designed computer interfaces. Free and open-sourced mapping tools such as Google Earth, Map Quest, open street maps etc, are reaching out to those who would have previously been excluded from cartographic activities and geographic information science. The juxtaposition of traditional static maps against a variety of new geovisulizations, map hacks, **crowd sourced content**, and **map mashups** illuminates how any particular map can provide a singular perspective of geographic phenomena and not a universal unyielding and explicit truth.

William Cartwright (2002), former president of the International Cartographic Association [ICA], posits that the cartographic industry has shifted from a model wherein maps are made in bulk to meet a predicted market demand to a model where maps are made on demand, often *in situ* (Cartwright 2002). The capacities of an extensive online geospatial infrastructure, coupled with location aware devices have created a new role for regular individuals as empowered cartographic creators. Crowd-sourcing technologies also allow web-connected individuals to skirt formal production channels and integrate data from their daily lives directly into cartographic products. Users can update and enhance maps at will and participate in the creation of a publicly developed map product. The benefits of crowdsourcing technologies is immense for those like non-sighted individuals whose data needs may not reflect the traditional map user.

Public access and participation in governmental GIS projects is touted as one mode of mapping practices that is acting to change the nature of contemporary governance. Public Participation GIS [**ppGIS]** is a form of GIS that openly engages users through the internet and allows for the direct consultation of constituents about relevant policy decisions. As a group that is often disenfranchised through their lack of access to maps, non-sighted people stand to gain much from ppGIS and similar tools. However these tools must be designed with **universal design** premises in mind if they are to meet this goal.

The need for technologies that can be used *in situ* to support and enhance navigation activities has also created a strong imperative to produce geographic products that are highly portable. The mobile technologies industry has also made significant investments into the development of small-form factor or handheld yet extremely information rich devices that provide an energetic platform for non-visual cartography. Indeed, a wide variety of smart phones and personal digital devices embody characteristics that are highly sought after for non-visual cartography, such as touch sensitivity (e.g. iPhones) haptic feedback, voice interaction, data storage and web access, portability and wireless hardware accommodations (i.e. Bluetooth). Indeed, mobile platforms like the Apple iPad integrate many of the device characteristics and features that have been used in previous efforts in non-visual cartographic research into a highly portable package. Building upon on this development momentum could stand as a very beneficial approach for propelling this field of research.

Maps, as forms of self expression, allow people to tell stories about their lives, experiences and surroundings (Mei-Po Kwan in Wilson and Poore 2009). Exclusion from these practices prevents the integration of non-mainstream lives into geographic discourse and weakens the depth of the shared awareness of space cartography is meant to achieve. Consider, for instance, the exclusion from geospatial activities experienced by non-sighted people as a result of their lack of access to serviceable map products. This exclusion is tremendous as non-sighted people are at once unable to meet their needs for geographic knowledge and unable to share and articulate intimate and unique experiences of geography. Furthermore, sighted people who cannot share these articulations are thus blinded by their own sight and excluded from the non-sighted worldview. Noe (2004) posits:

> "For those who see, it is difficult to resist the idea that being blind is like being in the dark. When we think of blindness this way, we imagine it as a state of blackness, absence and deprivation. We suppose that there is a gigantic hole in the consciousness of a blind person, a permanent feeling of incompleteness. Where there could be light, there is no light. This is a false picture of the nature of blindness. (p. 3)"

Empowering non-sighted individuals to achieve self-expression through mapping is one way to dispel these misconceptions.

2.8 Chapter Conclusion:

Each of the eras explored in this chapter embodies the transcendence of a previously established mode of mapping practice, the development of a new school of cartographic thought, and an opportunity for innovation towards novel research approaches. In the spirit of critical evaluation, these discussions must be used to illustrate how circumstances affecting non-visual cartography have arisen as well as what alternatives exist. Each of these traditions has an imperative that must be recognized to successfully advance non-visual cartographic efforts. These imperatives are summarized in Table 2-1.

Tradition	**Imperative**
Maps tend to look and feel how the author wants them to, but this is not always how the user needs them to look and feel. This places non-sighted people in a compromised position.	Each user or user groups' needs and capacities must ultimately define and drive how maps are designed.
Visual primacy and a maps-as-pictures approach limits how we think of maps. We avoid exploring alternatives that don't look like maps because we don't consider them to actually be maps. In this way, visual primacy has caused a detrimental form of path determinacy.	Non-Visual maps will not be directly analogous transpositions of visual maps. They must be wholly suitable and intentionally designed for their task.
Positivist approaches in cartography limit research variables to that which can be readily measured, observed and modeled. Oftentimes this perspective is too narrow and limits the scope of the variables that are identified.	Attempting to refine a model that is not appropriate will not yield success. The correct variables in a problem must be identified before solutions can be tested and optimized.
Maps have falsely been cast as vehicles for information that passively provide recipients with information. There has not been enough recognition for individuals' need to interact with maps in order to create their own knowledge and understanding.	Maps must be seen as tools that actively afford their user with value in practice through a wide variety of subtle behaviors and interactions. These practices are as important to the maps utility as the maps content itself.
Computers and their interfaces are not neutral publication platforms for maps. They are inextricable mediators of mapping activities and must be designed to enable the necessary behaviors and interactions that allow a user to create personal knowledge, meaning and understanding.	Computer hardware intended for non-visual mapping use must have interfaces that are explicitly designed to enable specific interactions. It must be recognized that the creation of in interface is the means to an end, but not the end itself.
Maps are simply a single element of a larger mapping paradigm that integrates both the way the map is created and the way the map can be used.	The study of non-visual maps must critically investigate more than just the physical map product; it must address the processes of cartography and cartographicy as well.

Table 2-1 Cartographic traditions and imperatives

3 Technical Research in Non-Visual Cartography

3.1 Introduction

In their ‘New Manifesto for Map studies’ Dodge, Perkins and Kitchin (2009) suggest that as part of moving forward, cartography must begin to investigate the materiality of maps, meaning “how the physicality of their production affords particular solutions to problems” (p 229). Investigating the physical design, implementation, and practicalities of non-visual mapping systems, in terms of how their production affords particular solutions to problems, can reveal much about what changes should be made in new systems to achieve success. Further to this, they also assert that moments of mapping failure are also worth investigating as “the moment when things go wrong often highlights how things really work (p. 234).”

The spectrum of research topics related to non-visual cartography is quite expansive, but there is much value to be gained from a comprehensive review. Non-visual cartography is a highly heterogeneous field that can be seen as a complex system of research involving many different categories of knowledge. Given that complex systems can rarely be understood by examining their components in isolation cognitive scientist David Marr (1982) suggests that we must “contemplate different levels of description that are linked, at least in principle, into a cohesive whole, even if linking the levels in complete detail is impractical. (p. 19)”

This chapter will provide a survey of findings from background research relevant to this thesis investigation. It will review the progress of non-visual cartography research to date in order to identify gaps, unachieved goals, promising findings and unsuccessful approaches. An awareness of these factors will be useful when conceptualizing potential new avenues for research that expands the range of map options available to non-sighted people. Additionally, this review will draw attention to the hallmarks and implications of particular research paradigms and guiding assumptions that are exhibited in non-visual cartographic research.

3.2 Map Operation Theory

To evaluate Tobin’s perspective that information availability facilitates goal achievement, as presented in section 1.3.1, an understanding of map operation theory is necessary. Corner (in Cosgrove 1999) provides a framework for separating the operational aspect of maps into three categories: fields, extracts and plotting. Corner’s operational components moderate the quality and quantity of geographic information that a map or GIS makes available (i.e. variables a,b and c in Tobin's formula, y=f(a,b,c), for information availability). It is hoped that by exposing these three essential operational categories, individual sections in the following review of non-visual cartographic research may be seen in a more holistic and complete context.

3.2.1 Fields

The field of a map is the surface or area where content is presented. It is analogous to the actual ground or space of a mapped environment. Examples of fields include the paper or monitor the map is drawn upon, the body of a globe, or a block of plastic from which a relief model is carved. It is the point of contact between a map and its audience that may be observed and examined to find information.

The field is also the "system within which the extracts will later be organized" (p. 229) (Corner 1999). It defines the view extent, orientation and perspective, central coordinates, scale, units of measure and the geographic projection. Altering field parameters can affect a map by changing what content is made apparent and how it is organized. Corner emphasizes that a field that has multiple frameworks (such as a map that depicts content graphically, tactilely and audibly) is likely to be much more inclusive than a singular closed system. Furthermore, he posits that a field that breaks with tradition is more likely to precipitate new findings and understandings of geography than one that is more routine and conventional. Consequently, a great deal of research emphasis, much of it very positivistic and filtering-loss oriented, has been directed towards the study of map fields and potential rendering formats. Research seeking advancements in area of map rendering formats generally investigates what modalities, hardware, software or publishing methods provide the best non-visual information presentation platform.

3.2.2 Extracts

Golledge (1993) suggests that spatial phenomena appear as sets of occurrences that we label in order to identify. These occurrences are the extracts that can be represented and observed on the map field. The term extracts is used because these pieces of data are always "selected, isolated and pulled-out from their seamlessness with other things" (p. 230) (Corner 1999). They include distinct feature objects but may also relate other data and attributes, such as quantities, velocities, forces, densities, trajectories, intensities and extents. When extracts are teased out of their neutral geographic reality they may be juxtaposed with other entities in the field in order to present conspicuous patterns and arrangements of data.

The selection and arrangement of cartographic extracts significantly affects how meaningful a given map may be to an individual, as well as how easily the represented spatial data can be internalized. For instance, the extraction of data about the texture and relief of a pathway surface may be highly meaningful to non-sighted people and may contribute to their spatial awareness of an area much more so than visual extracts like color or shape would.

3.2.3 Plottings

Plottings entail the drawing out or treatment of different relationships that can be observed among extracts rendered within the field. For example, creating a line that illustrates a path or route between two locations, highlighting regions that show a higher intensity of a certain variable than adjacent regions, or systematically labeling features using a specific taxonomy are all examples of plotting operations. These treatment techniques may be used for analysis or to express insight about a geographic condition or phenomenon by setting out certain pieces of data in relation to others. Again, the choice of plotting technique used may significantly affect the meaningfulness of a map and how viably an individual may interact with it to create their own knowledge. For instance, a non-sighted person who encounters map features serially or one at a time through tactile exploration may be much less able than a person with full synoptic vision to detect broad changes across a series of data points even though differences between two individual points may be easily detected. As such, different or multiple plotting techniques must be considered to create viably accessible maps for all users.

3.3 Map Production Methods

The first major category of research in this field investigates various map production methods that provide different ways for non-sighted people to access spatial information. Maps that do not rely on visual representation have existed throughout history. For instance, the Ammassalik Inuit bone carvings (Figure 2.9) and Maori stick charts of the Marshall islands (Best 1976) (Figure Figure 3.1) exemplify pre-modern methods of sharing geographic knowledge without pictorial imagery. This may be taken as the first evidence that the use of alternatives to visual representation in geography is neither novel nor impractical[7]. Nevertheless, contemporary research has largely focused on tactile maps, which are tangible diagrams explored via touch rather than vision (Aldrich et al. 2003). These maps rely on palpable textures and surficial variations, such as raised lines, dots, shapes and patterns, to create discernible map features. However, tactile maps inspired and now compete with many alternatives.

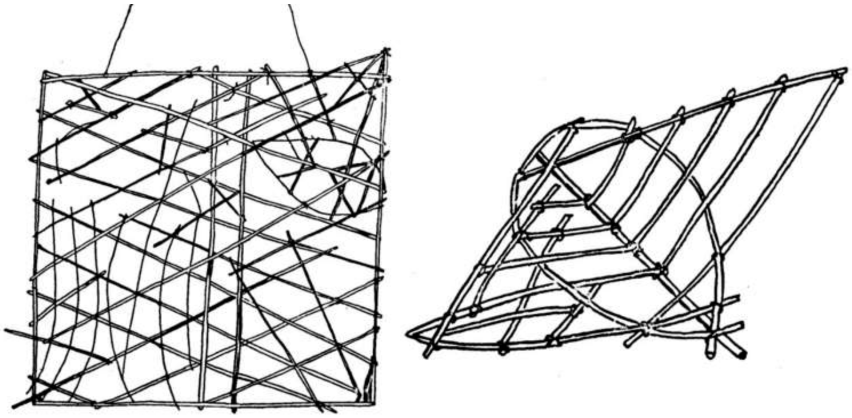

Figure 3.1 Stick charts from the Marshall Islands of Micronesia. Redrawn from Best (1976).

Technological approaches that use personal computers and custom human computer interfaces to depict spatial information to non-sighted users have also been pursued. Some research efforts advance uni-modal forms of representation while others attempt to blend a variety of sensory stimulations to create multi-modal representations. Examples of this most recent trend towards multi-modal technological fixes include the haptic mouse, 3D printing, audio tactile devices and automatic map generation (Ungar 2006).

3.3.1 Tactile Maps

Tactile maps are diagrammatic representations, typically created on paper or a rigid plate, that are read principally by touch (Figure 3.2). Other products such as textured globes and sculpted relief maps are also examples of tactile maps. Tactile maps are, in many ways, the most direct analog to visual maps. The ease and simplicity of developing this type of map using visual maps as a template has made it one of the most enduring forms of non-visual geographic products. Techniques for producing tactile maps include **craft production**, **casting**, **etching**, **embossing**, **vacuum forming**, and **3D printing** (Vozenilek et al. 2009, Perkins 2002). All of these processes

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[7] It is worth noting that perspectives exist which suggest that physiological fixes, such as focusing solely on medical research to restore sight, are more effective avenues towards solving the issue of access in geography.

create a permanent representation of a geographic scene using tactile representation attributes Figure 3.3 where every extract or feature is physically differentiated from the map's background and adjacent content. This differentiation is primarily achieved through texture variations that make some features stand out or sink into the surface. However, other characteristics such as feature form, width and protrusion profiles (Dinar, Rowell and McCallum 2005) and surface tactile phenomena (Merleau-Ponty 2002) (Section 1.3.2) may also be used as representative variables.

Figure 3.2 A static tactile relief map created using a vacuum forming technique. (Coll Escanilla, Perez de Prada and Pino Silva 2009)

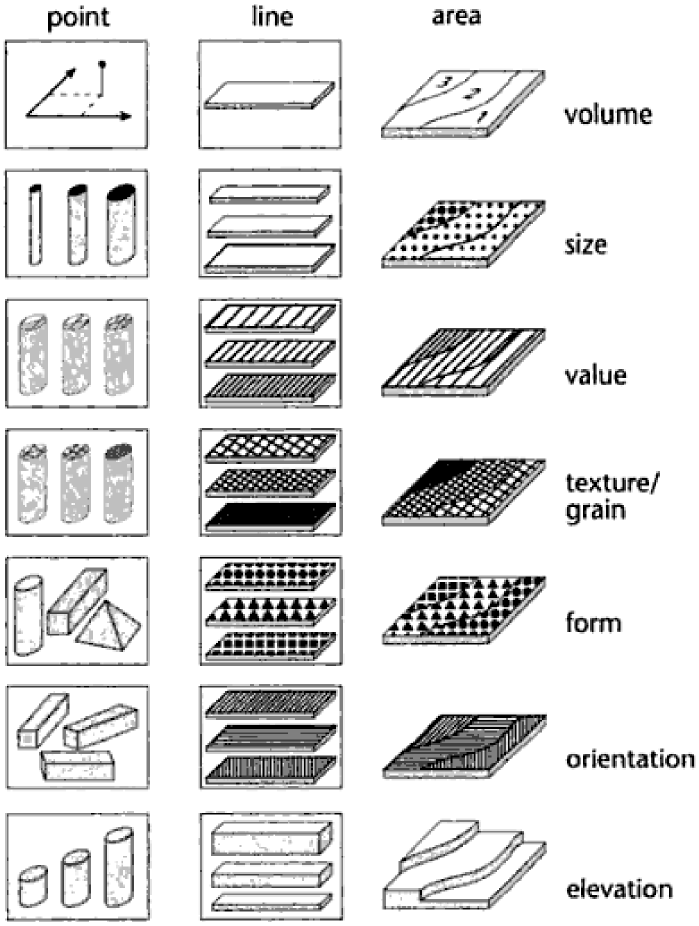

Figure 3.3 Vasconcellos' tactile map attributes matched to Bertin's original seven graphic variables. (MacEacheran 1995)

Tatham (2003) suggests that the evolution of tactile mapping has been propelled by advances in the automation of map production through the twentieth century. Like the printing press, automated tactile production technologies improved output and increased the demand for and availability of tactile map products. Ungar’s (2006) editorial survey of the evolution of non-visual cartographic research posited that automating tactile map production also allowed effort and attention that would otherwise be devoted to the labour of manual crafting to be refocused on other design issues. Furthermore, mechanical automation liberated the production of tactile maps from the hands of specialists and allowed individuals from a wider range of backgrounds, such as psychology, pedagogy, geography, engineering, etc, to contribute their expertise to the development of tactile maps and non-visual cartography. Perkins (2002) notes, however, that despite advancements in tactile printing technologies, the cost of production remains high. The size of most print runs is constrained by the limited budgets of sponsoring organizations and a much smaller market to drive consumer demand.

Tactile maps are the most widely used and studied forms of non-visual maps. They are relatively convenient to produce, easy to explore, and integrate Braille labeling. However, this form of labeling can be troublesome as Braille literacy is diminishing within the non-sighted population, requires extensive practice to develop, and may be unattainable for individuals with low tactile sensitivity.

The simplicity of tactile maps, combined with their similarities to pictorial maps, makes them effective learning tools in classroom settings. Tactile maps benefit from good legibility and readability qualities, but may suffer from low levels of content density, material intensive production, and are limited to singular depictions. While tactile maps are generally as portable as ink on paper representations, they are susceptible to increased wear and tear that results from manual tactile exploration and storage difficulties.

Tactile map production methods are well suited to empirical investigation as it is relatively easy to change tactile variables on raised line maps and test uptake effectiveness against a control group. It is important to consider, however, that although performance trends may be measurable for particular aspects of each tactile map type, preferences vary widely among users. Maps that may be the most effective in a single task still may not be the most desirable or preferable to use in general (Erin 2009).

Like printed visual maps, tactile maps are inherently static. The scenes they depict cannot be changed without replacing the entire map. Static map products typically cannot provide as much information as digital mapping systems, which can present spatial data using multiple sensory modalities, enable access to multiple map scenes from one device and do not rely on Braille text.

3.3.2 Multimodal Computer Mapping Systems

The introduction of computer technologies for non-visual mapping has enriched non-visual cartography in many ways. Computers allow for more diverse interaction opportunities than tactile maps and provide dynamic representations of spatial information across a variety of different sensory modalities. Novel interaction opportunities include the ability to employ tactile, haptic and auditory interaction modalities, alone or in combination, to access enhanced spatial data representations. Computer mapping devices are discussed in the following sections according to these listed modalities of sensory engagement.

3.3.2.1 Touch-centric Computer Interfaces

Touch-centric computer interfaces, like tactile maps, use physical touch and body position as the primary means of sensory engagement. Computer interfaces of this sort can be separated into three families: the first includes tactile display devices that are able to dynamically change their physical form in order to generate different tangible representations of spatial information on command; the second includes touch sensitive computer input devices that dynamically respond when touched by a user; the third includes computer vision based motion capture devices that track the position of a user's fingers, hands and/or body through space.

3.3.2.1.1 Tactile Displays

Tactile displays attempt to integrate the physical rendering characteristics and design variables of tactile maps into a platform that allows different scenes to be loaded and depicted, as if they were depicted on a standard computer monitor. Many tactile display devices build upon Braille text output devices, which represent Braille lettering symbols using computer adjustable pins to create different patterns. Other examples of tangible display devices include surfaces that swell or contract (Figure 3.4), mice that provide cutaneous skin stimulation to the finger tips via pins, vibrating transducers or electrodes. These devices are meant to simulate the experience the fingertip passing over tactile features as the hand moves across a surface[8].

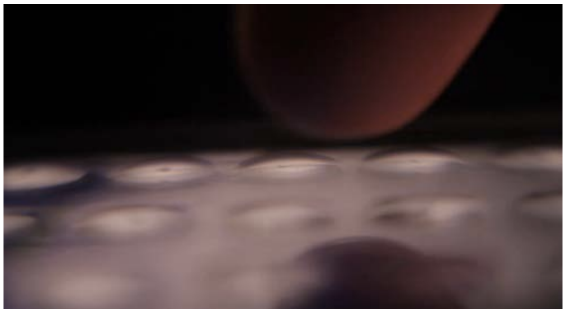

Figure 3.4 Tactus Technologies refreshable tactile display surface (Ciesla 2012)

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[8] Other forms of tangible display devices that rely on cutaneous stimulation in one area of the skin, such as the Opticon device (Redfearn, J. (1975) Augmenting human senses. *Physics in Technology*, 6**,** 231., do exist but are not discussed here given their predominantly aspatial modes of representation.

Rendering flexibility and experiential similarity to Braille lettering are strengths for tangible display devices, but they are limited by poor content density and resolution. Furthermore, many devices of this type cannot effectively represent smooth contiguous features like lines or polygons using pin patterns. Finally, refreshable tactile display devices can be very cumbersome, difficult to manufacture, expensive, and power hungry, particularly if motors, actuators and transducers are required.

3.3.2.1.2 Touch Sensitive Devices

Touch sensitive devices detect pressure or motion when a user's fingers touch a sensor surface and then provide feedback through a secondary sensory modality, like a display screen, haptic device or speakers. The trackpads and touch screens used in notebook and tablet computers are the clearest example of this type of sensor, though versions for non-visual and mapping purposes are generally many times larger.

Touch sensitive devices offer many benefits for use in non-visual cartography. They allow the field of a flat map surface to be superimposed upon a touch sensor so that the boundary of the map and the boundary of the touchpad are aligned. Touching any location on the sensor surface then provides information about the corresponding map location. The provision of an absolute frame of kinesthetic reference is a valuable benefit that the mice typically used to control computers, which only track relative motion, cannot offer. As long as the user remains in contact with the map, secondary feedback can be continuously provided as well, which allows a form of tracing exploration. Some devices, such as talking tactile tablets allow certain static tactile maps, generally made of paper or light plastic, to be overlaid directly onto the touch surface. This affordance adds touch interactivity to a previously inactive rendering.

Touch sensitive devices can also use gestures and multi-touch interactions for system control, map exploration and manipulation. Gesture interactions, such as circling, swiping, stretching, etc. (Hagedorn 2009) allow users to query map features and activate interactive tools in place with their hands directly on the map at a point of interest. This reduces the possibility for confusion that occurs when a disorienting shift to a keyboard or button panel is required. Multi-touch interactions expand the user's sensory aperture and points of bodily contact with the map from one to many fingers or one to both hands. Research indicates that **bimanual**, or two handed, map exploration is preferable to **unimanual** exploration and may lead to increased map comprehension (Lindeman 1999).

One limitation of touch sensitive devices is that they are much better at conveying areal qualities than geometric properties. For instance, touching a point on a touch sensitive world map will provide information about the country that occupies that location. Yet it cannot easily convey the relative position of that location within the country or even the shape of the region it occupies.

3.3.2.1.3 Motion Capture Devices

Motion capture devices have the ability to track a point of contact within a Euclidean coordinate system. Motion capture devices accomplish this same feat using computer vision technologies that watch the movement of body parts within a calibrated field of view. The output of this process is quite similar to that of touch sensitive devices that track instances of contact and motion across a field of sensors. In fact, many motion capture devices that can be used for mapping purposes were developed as alternatives to traditional electronic whiteboard designs (Chen and Sun 2009).

Motion capture devices are constrained by many of the same limitations as touch sensitive devices, such as a bias towards areal rather than geometric information. However, they differ in that they do not require sensors and tracking equipment to be physically embedded where the map field is deployed and explored. The advantages of this quality are twofold. Firstly, any surface that can be targeted within the viewfinder of a digital camera can be used as a deployment space for a digital map or computing surface. This provides opportunities for a level of platform portability comparable to static tactile maps, while maintaining the interactivity found in touch sensitive devices (Mistry and Maes 2009). The removal of excessive interface hardware is also an advantage of this family of devices as it makes the users' own hands effectors within the interface system and removes the possibility of misplacing, damaging or otherwise disconnecting particular components.

Secondly, the removal of the body tracing system from the map field space allows other non-sensory equipment to be placed where touch sensors would otherwise go. Many motion capture systems operate by orienting the camera from overhead or with an orthogonal perspective to the intended map field. A static tactile map, a tangible display, or novel interface equipment can then be used to great advantage in this available space. Pielot et al. (2007) demonstrate this affordance in a system intended for tangible exploration of auditory city maps. By creating a motion capture environment where movement within a virtual map is tracked from above, the user is able to move a familiar **avatar** object – a toy duck - within the map field in order roam and explore new sound cues associated with certain map locations (Figure 3.5).

Figure 3.5 Participant demonstrating the use of Pielot et al's (2007) motion capture and artefact based auditory mapping system. This figure depicts a motion capture apparatus used to track the position of the interface avatar (left), a user exploring a map scene by moving the interface avatar (centre), and a rendering of the user's movement within the virtual map scene (right).

3.3.2.2 Haptic Computer Interfaces

Haptic devices are those that can exert a direct force on their users. They artificially recreate the kinesthetic sensations associated with manual physical exploration. Haptic devices can simulate many different virtual shapes and objects by generating forces akin to those experienced when exploring a genuine object like a tactile map. They may even provide sensations that do not obey real-world physics, such as weightlessness, solid-object permeability, and sounds that do not echo or decay. Physical properties such as pressure, texture, surface permeability, softness or hardness, malleability, ductility, friction, adhesion, repulsion, vibration, and many different types of shape profile variation may be altered to simulate a wide variety of representative models for spatial information (Hayward et al. 2004).

Kinesthetic interactions with haptic devices are defined by each unit's possible degrees of freedom, which denote the orientation, position and axis of rotation of a device's input hardware, often called an effector. An effector is a point of contact in a haptic interface where mechanical forces are exerted between to the human body and computer interface. By manipulating an effector a user can, in effect, touch a virtual object or model in order to feel and obtain information about its shape, position and arrangement relative to other virtual features.

Iwata (2008) identifies three different categories of haptic technologies: exoskeleton, tool-handling, and object oriented devices. Exoskeleton style devices are worn like clothing on a hand, limb or over their whole body. They track and restrain the user's position and movements to simulate contact when touching a virtual object. For example, by stopping the downward motion of a user's fingers, hand and/or arm, the sensation of touching an object sitting on the ground or a table top could be created. In mapping situations, these devices can be used to touch and interact with terrain and built features in scaled 3D landscape models.

Tool-handling devices place an effector apparatus, such as a pen, joystick, mouse or puck, directly in the users hand, which the computer can track and actively move using force-feedback mechanisms. This type of device is often used as a positional probe that can touch or trace features on a 2D map surface like a river, road or coastline. The tip of a tool may also be used to direct the movement of an avatar or active cursor within a map scene and elicit tactile feedback from touching a feature (e.g. different rough surfaces indicate regions on land, while a smooth surface indicates water (Jansson, Imre and Cammilton 2006)). Alternatively, the speed of the object in a users hand may change to simulate friction variations when moving across a map surface.

Object oriented haptic interfaces incorporate mechanical components that can change orientation or move to approximate the shape of a modeled object. For instance, Ridenklau's (2010a) object oriented haptic device integrates motorized blocks that reposition themselves to match distributions of data in a scatter plot graph (Figure 3.6). While they are not well suited to complex spatial arrangements, devices of this sort provide the means to explore basic shapes and spatial feature arrangements.

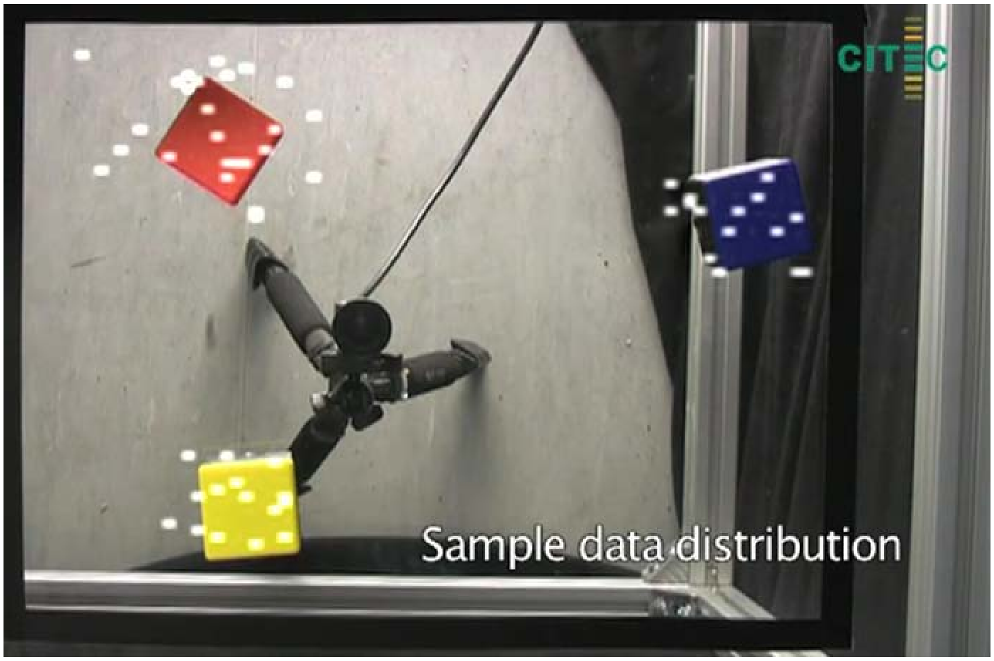


Figure 3.6 Tangible Active Objects, shown in red, yellow and blue, organized to convey the location of data cluster distributions in a scatter plot, shown as white points (Riedenklau, Ritter and Hermann 2010b).

Haptic devices provide many benefits to users exploring spatial information, but are not without limitations. The mechanically active nature of force feedback devices can also be used to provide assisted learning by physically guiding a user along an unfamiliar path between locations on a map (Furner 2009). This form of automated aid can reduce the need for human assistance, but may also be confusing if a usable frame of reference is not maintained while the motion is carried out.

Research efforts have shown that non-sighted haptic device users are able to perceive and interpret informative diagrams such as line and bar graphs or pie charts (Wall and Brewster 2004). These studies found that the perception of haptic graph representations was more accurate than static tactile explorations, particularly when used with complementary audio feedback, but exploration times were significantly slower. The value of being able to access rich and refreshable digital information, therefore, comes with a price of increased effort expended in use. Providing digital markers that serve as memory aids when exploring such scenes could decrease cognitive exertion and increases speed, but is difficult to implement in practice. Users testing particular haptic devices have also experienced confusion as a result of unfamiliar, confusing or insufficient stimuli (Tan 2000). Using a haptic device may be akin to exploring a detailed sculpture underneath a blanket or while wearing a thick glove. Likewise, simple devices may not provide enough points of contact to meaningfully assess an object (Kahol and Panchanathan 2006). Other more complicated devices may provide too many points of stimuli, which can confuse the users.

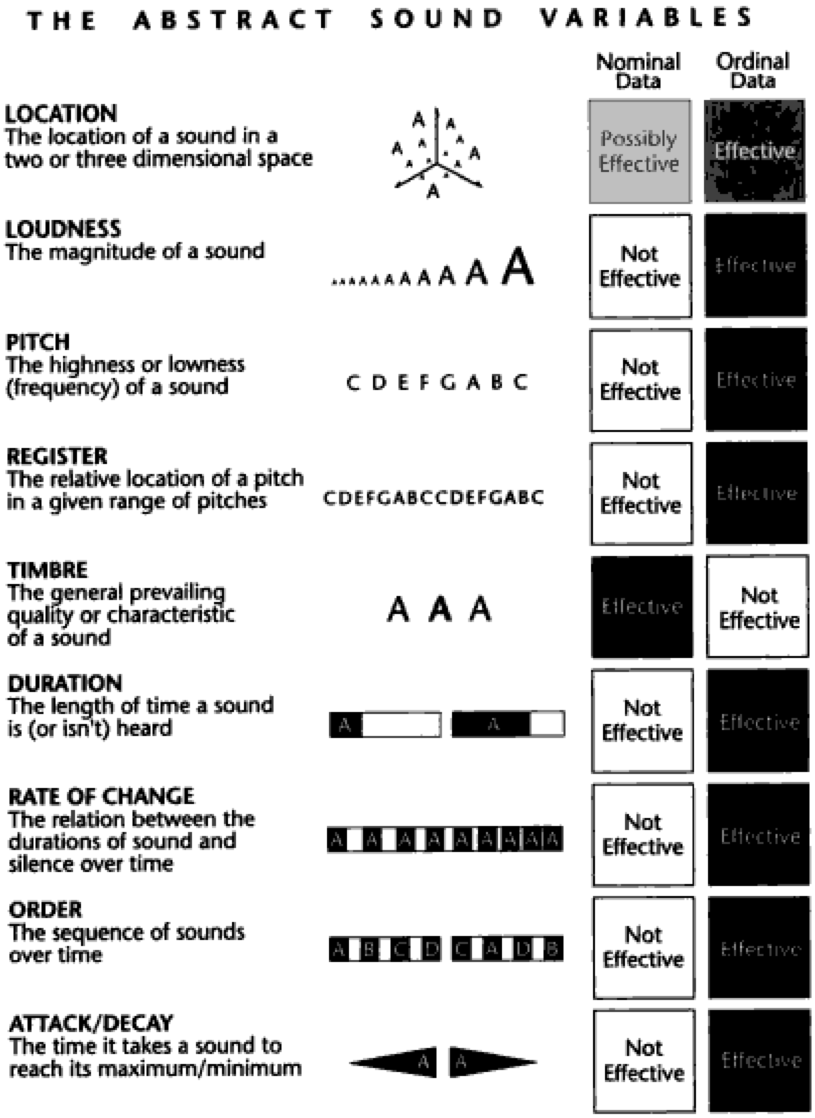
From an investigative perspective haptic devices are tremendously useful for the study of non-visual map exploration since a user's actions and the computer's output can be recorded and played back for review and analysis at a later time. Many haptic devices also allow more comprehensive or innovative forms of diagnostic testing to assess the geographic learning a user achieved. For instance, participant trials can be recorded and replayed for later review along with other calculated measurements such as distances traveled during exploration. Accurately assessing the utility of haptic devices may be complicated by a number of factors. Studies have indicated that haptic discrimination and sensation is highly subject to learning and practice effects and may be mitigated by illusory phenomena and the limitations of the human psycho-sensory systems (Grunwald 2008).

3.3.2.3 Auditory Interfaces

Auditory interfaces represent spatial information through sound and speech. Sound is one of the most readily perceptible forms of stimuli and is often used for direct communication. Audio has been extensively investigated as a channel for accessing geographic information. Aural encoding can achieve extremely high levels of content density and fidelity and can be easily stored and transmitted. Unlike tactile and haptic production technologies, technologies for producing and sharing information rich audio are already entrenched in contemporary society. For instance, music and the performing arts have brought about highly sophisticated recording, processing, storage and distribution methods, such as multi-layered audio, digital encoding formats like mp3, and many different distribution media (e.g. iPods, dvds, cd's vinyl, or cassette tapes). Likewise, the computer gaming and film industries have prompted the development of sophisticated virtual audio environments and surround sound systems.

Together these factors lend themselves well to the task of encoding spatial data. However, sonification, more so than any other mode of information encoding, places the user in a very receptive role and reinforces the information conveyance paradigm. With only rare exceptions, users are limited to listening to audio playback and are unable to modify or interact directly with the content of the recordings or soundscapes they experience.

A wealth of information encoding possibilities is enabled by the extensive array of possible sound parameters (Figure 3.7). Factors that affect the usability of auditory representations include identifiability, conceptual mapping, physical parameters, and user preferences (Mynatt 1994). Different types of sound that can be used to encode spatial information include speech and narration, music, sound effects, and ambient or environmental sounds (Brauen 2006).



THE ABSTRACT SOUND VARIABLES

		Nominal Data	Ordinal Data
LOCATION The location of a sound in a two or three dimensional space		Possibly Effective	Effective
LOUDNESS The magnitude of a sound	AAAAAAAAAAA	Not Effective	Effective
PITCH The highness or lowness (frequency) of a sound	C D E F G A B C	Not Effective	Effective
REGISTER The relative location of a pitch in a given range of pitches	CDEFGABCCDEFGABC	Not Effective	Effective
TIMBRE The general prevailing quality or characteristic of a sound	A A A	Effective	Not Effective
DURATION The length of time a sound is (or isn't) heard	A A	Not Effective	Effective
RATE OF CHANGE The relation between the durations of sound and silence over time	A A A A A A A A A	Not Effective	Effective
ORDER The sequence of sounds over time	A B C D C A D B	Not Effective	Effective
ATTACK/DECAY The time it takes a sound to reach its maximum/minimum	A A	Not Effective	Effective

Figure 3.7 MacEacheran's (1995) diagram of abstract sound variables based on Krygier's typogology.

Information sonification can be highly localized, sequential, and symbolic or generalized, instantaneous, and ambient. For instance, an individual standing in a park may be aware of many sounds emanating from a variety of sources (e.g. children playing, birds singing, footsteps on pathways, wind in trees) and gains information about the surrounding landscape when each sound is recognized and located. Conversely, listening to an audiobook through headphones allows for higher level learning as one processes messages over time, but it may not provide any external spatial cues by changing the perceived source location of a sound.

The way a sound is presented to the listener can affect its qualities. Headphones that provide stereo or binaural sound employ a premise known as the head related transfer function [HRTF] to seemingly project sounds into space around a listener's body (Belardinelli et al. 2009) This concept is based upon the brain's ability to distinguish differences between sounds that reach each ear from a single source. By using positioning algorithms to alter the timing, volume and pitch of sounds played back through either side of a pair of headphones, sounds can be made to seem near or farther away and positioned around the listener's body.

In addition to HRTF technologies, surround sound systems have also been used to provide a sense of spatialization to audio information. These systems, which are used extensively for home theatre and video gaming applications, arrange a number of loud speakers around a room and then direct different channels of audio to each speaker (Alonso et al. 2006). This allows sounds to be emitted at different locations or moved in relation to the listener. One difficulty presented by these systems is that they are typically constructed to be level with a user and not above or below. Since the user is located within the projected soundscape, they are also limited to the creation of egocentric soundscapes.

The human brain and body are also pre-tuned to the spatial nature of sound in order to determine the relative location of sound sources. Many non-sighted people have demonstrated that their sense of hearing becomes more acute after vision loss, particularly when the loss occurred at an early age (Gougoux et al. 2004). The spatialization of sounds can provide many benefits in geographic applications. Users practicing a route between two locations using a touch tablet can be given sound cues to follow (e.g. keep the sound of the river on your left and travel toward the sound of a church bell). Alternately, a user who places a finger or haptic probe on a touch surface and hears the sound of waves or running water can infer that some form of lake, ocean, or river is present at that location on the map.

As with visual symbols, the sounds used for representative encoding with non-speech audio must be learned through practice or from a provided reference legend, since the metaphors defining each symbol must have a readily apparent meaning to convey data clearly.

Speech recognition is recognized as one of most intuitive interaction channels available to support non-visual cartography (Jacobson 2004). Speech interaction can be unidirectional if the user can only listen to narration, or bidirectional when used as a form of command input if the device is capable of speech recognition. Screen readers such as the JAWS program (Hamilton 2012) are often used to convert text that would be printed on-screen into vocalizations. Many devices such as handheld GPS units and mobile phones already use automatic text to speech output to provide traveling directions and command prompts in a hands-free/eyes-free system.

For all the flexibility and robust output that sonification provides it is often much better at conveying information *about* spatial data than portraying the data itself. For instance, a user who is exploring a sound enhanced map may be able to recognize symbolic **earcons** and label vocalizations to determine what country they are targeting on a map but it is very difficult to determine the shape of a region using proprioception and sound cues alone. For this reason, sonification must generally be used in conjunction with other modalities to create a more complete spatial representation.

3.3.2.4 Immersive Interfaces

The use of computers, particularly those with multi-modal interfaces, to present geographic information provides a wider range of user experiences than traditional hard copy maps. Often these approaches attempt to orient the user away from a traditional on-screen interface that is complemented by extra forms of sensory feedback and instead engage them with an artificial yet highly immersive virtual environment. With these systems, maps can be presented as partially or fully immersive scenes that allow users to pre-explore foreign landscapes without the difficulty or danger of visiting unfamiliar locations in person.

Haptic Soundscapes and Virtual Reality [VR] interfaces are examples of immersive multi-modal approaches that integrate two or more sensory channels to create richer and more natural information access environments. Haptic soundscapes are akin to geographic reference products used for navigation and orientation while virtual reality environments offer a more complete vicarious exploratory experience that can be used for familiarization with foreign locales.

Experientially, haptic soundscapes are less fully immersive than virtual reality interfaces, but both are more immersive than traditional modes of non-visual representation like tactile maps. There are fundamental differences between fully and partially immersive user experiences (Kjeldskov 2001). Partial immersion provides an externalized third person perspective and supports a feeling of 'looking at' a mapped scene. Fully immersive virtual reality representations provide a first person perspective and create the feeling of "being in an environment or landscape (p. 587)."

3.3.2.5 Haptic Soundscapes

Haptic soundscape maps provide representations of spatial data using multimodal computer interfaces that offer haptic and auditory sensory feedback. Users are able to dynamically touch, feel and hear an artificial map scene derived from the same spatial data files used to make flat visual maps. Haptic soundscapes often employ programming tools like **extensible mark-up languages** [XML] to create representation schemes or **stylesheets** that define haptic and auditory output characteristics for vector GIS data in the same way that colour or shading stylesheets are defined for visual maps. The ability to rapidly create and access maps that offer meaningful non-visual stimuli from standard GIS data is a major accessibility benefit of haptic soundscapes as it removes the need for skilled experts to carefully prepare custom tactile map products. Furthermore, the data needed to generate these maps can be distributed through the internet, which supports access to new and more up to date spatial information. Haptic soundscapes can also be used to portray artificial spatial constructs like arrows and gridlines, or cartographic abstractions, such as cartograms.

Haptic soundscape users may experience difficulty adapting to a very unfamiliar mode of exploration. Most users are not accustomed to observing a landscape's features, such as roads, buildings, coastlines, etc. by touch, thus a large amount of cognitive effort is required to interpret the feedback obtained through haptic explorations.

Examples of prototype haptic soundscape maps include Simonnet et al.'s (2007) SeaTouch system, which provides wayfinding information for visually impaired sailors. This system utilizes the sensible Phantom Omni haptic pen and allows users to explore haptic representations of water and coastlines in relation to their boat while listening for audio proximity cues and localized sounds from navigational buoys and landmarks. Campus maps produced by the University of Wisconsin-Madison (Vanderheiden 1996) and the University of Oregon (Lawrence, Martinelli and Nehmer 2009) are also examples of haptic soundscapes. These maps offer transposed versions of the standard campus maps that can be explored using a haptic mouse.

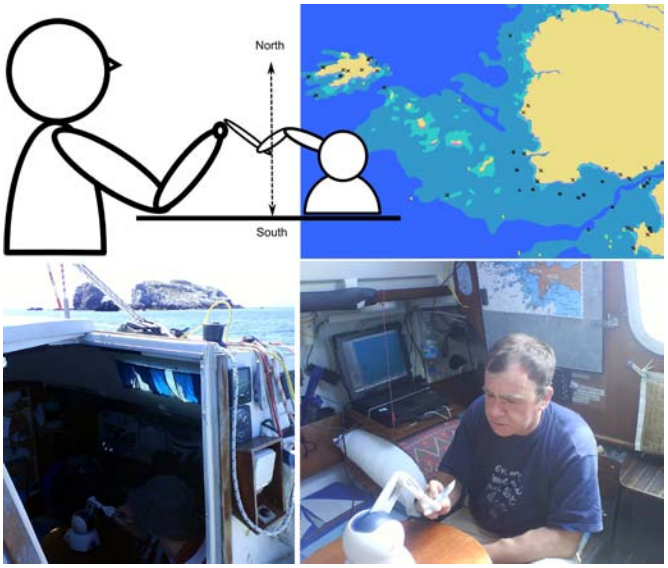


Figure 3.8 Simonnet's et al’s (2007) SeaTouch interface used by visually impaired sailors.

VR interfaces allow the user to move within a three dimensional space and interact with encountered features as if they were real. For non sighted users this can be a practical way of visiting remote environments and locations to experience what might be encountered there in a safer and less chaotic manner. In many ways, virtual reality provides the most immediately familiar way for non-sighted people to negotiate representations of geographic information in that virtual reality interaction and real world interactions can be nearly identical. Ideally, exploring a VR landscape could be indistinguishable from authentic exploration.

Virtual reality systems also offer the possibility to alter and moderate content parameters as desired. This possibility can be used to enhance and improve virtual exploration experiences. This allows certain variables to be exaggerated or minimized in contrast to others. For instance, the expected volume of traffic noise from a busy road could be reduced to isolate the sounds of footsteps reflected off nearby walls when walking along a virtual sidewalk.

Due to the intense data processing needs and unique hardware, virtual reality systems can be very expensive and highly labour intensive for use as platforms for cartographic information. Additionally, virtual reality experiences are primarily egocentric and rely on first person perspectives within environments and therefore cannot easily present geographic information that is either allocentric by nature or more abstract, such as cartograms and thematic maps.

3.3.3 Near Field Haptic Technologies

A final area of technological development that has not yet been linked to non-visual carographic research is the field of near-surface haptic technologies, which create refreshable tactile output from within, or immediately above or below, a smooth interface surface. Technologies developed in this field have not yet been directly applied to non-visual cartographic research but there are many ways in which the concepts developed in this vein represent tremendous potential value for non-sighted people.

Two main groups have led recent developments in Near-Surface Haptic Technologies. The German research team from Aachen University leading the Fingerflux project is the first group of note in this field. The FigureFlux device (Weiss et al. 2011a) is a touch sensitive interface that has been augmented with subsurface electromagnets to create an interaction platform with magnetic tactile output (Figure 3.9). The impetus of this project was to create a user interface that reduces the effects of finger drift that can occur when a user's visual attention is not focused on the touch surface at hand.

The Japanese-American research group leading the Senseg project (Banter 2010) is the second major player in the field of near-surface haptic technologies. The Senseg display device creates a tactile sensation for the user by spreading a polarized charge across a flat touch surface. By varying the intensity, polarity and distribution of the surface charge, the Senseg Tixel display coating can effectively replicate many textures and tactile sensations, such as silken smoothness, rough grit, grooves, and ridges (Figure 3.10).

Figure 3.9 The Fingerflux magnetic display surface (Weiss et al. 2011b).

Figure 3.10 Senseg E-Screen device demonstrating different tactile sensations such as grit, ridges, corduroy and leather (Arthur 2012).

3.4 Human Factors Research

Human factors research in non-visual cartography examines how the body, its faculties and behaviours mediate the collection of spatial information from maps. This area of area of research has three subgroups: perception, exploration and cognition. Map perception involves the detection, identification, and discrimination of mapped features encountered by the body's sense organs. Exploration involves surveying a scene to search for new phenomena and probe what is found to gain further information. Map cognition involves an awareness of space and the construction of an informed mental model that integrates the configuration and attributes of elements found on a map. To date, human factors research has been mainly oriented towards developing map design guidelines that can improve information communication. Empirical methods are often used to observe and explore how users respond to the features and figures presented in test maps. Thus far, however, there has been little success in developing a concrete model of non-visual geographic cognition, and determining how these three factors operate in the context of knowledge synthesis.

Perkins (2002) notes that psychological investigations of spatial representations and perceptual abilities became a major component of research carried out in the 1990s. In previous eras, non-sighted people had been considered incapable of fully perceiving and understanding geographic materials due to hypothesized neurological deficiencies and or mental inefficiencies that were thought to result from a life without visual stimulation (Kitchin and Jacobson 1997). It is now understood, however, that individuals with impaired vision have the same general cognitive spatial abilities as sighted people (Maurer, Lewis and Mondloch 2005) but learn about geography in different ways. Open and sensitive inquiry into the specific differences between sighted and non-sighted people is necessary to ensure that meaningful maps are developed for both groups. Non-sighted people may have less complete configurational knowledge, due to their limited distal perception beyond their bodily reach and fewer supportive visual experiences (Kahol and Panchanathan 2006). Furthermore, non-sighted people must rely more heavily on serial forms of sensory interaction than sighted people, who can rely on synoptic visual perception. Synoptic perception involves a combined or holistic sensation of a phenomenon or environment, while serial perception involves the detection of individual stimuli events in a series over time.

Differences between these two sensory paradigms contribute to many difficulties in non-visual cartography.

These three human factor areas are often studied independently, but are nevertheless synergistic processes (Ackerman 2009, Lederman and Klatzky 2009). Separating factors as they are discussed here is conceptually possible, but not functionally. Each factor may be discussed independently, but cannot be studied or observed in isolation. Perception is facilitated by exploratory behaviours and supports cognitive processes. Exploration relies on perceptual feedback and cognitive guidance. Cognition requires perceptual input and is mediated by exploration patterns.

3.4.1 Perception:

The study of perception in non-visual cartography investigates how encoded spatial information is collected from maps via the body's sense organs. This area of research aims to evaluate how spatial information becomes evident to a map user and what practices can improve the content, formatting and operation of non-visual maps. Perceptual research in non-visual cartography typically involves manipulating fields, and extracting and plotting parameters[9], to evaluate the accessibility, meaningfulness, legibility and utility of the resulting map. While, at present, no single theory comprehensively explains how the human perceptual system works when using non-visual maps, a number of important discoveries about its function and limitations have been made. In particular, studies have shown that visual experience is not a necessity for the successful perception and cognition of non-visual geographic representations but difficulty does increase if either the task or target depiction are novel to the percipient (Heller 2002).

Meng (2008) suggests that information perception may involve multiple phases, or reflex levels. Each reflex level adds meaning to what has been perceived and contributes to a deeper awareness and intimacy with the encountered information. During the first reflex level of perception unconscious associations are made between basic stimuli and one or more primary forms of meaning. For instance, upon touching a shape feature on a tactile map basic meanings such as 'square' or 'box' may be associated with the stimuli. As further attention is expended new meanings are discovered. What was only a square shape is soon perceived to represent a building. Finally, subsequent perceptions refine understanding of the perceived geographic

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[9] As outlined by Corner, in section 3.2.1

scene and associate deeper meanings with discovered items. The square shape that was identified as a building may finally be perceived as a house or even one's own home. A breakdown at any intermediate level prevents the full reflex depth of a map from being attained. Basic sensory perception is said to involve at least three phases or reflex levels (Coren, Ward and Enns 2004):

1) the *detection* of a map's **invariants**, which are unique physical properties, such as the tactile, haptic and auditory variables outlined in Figure 3.3 and Figure 3.7;
2) the *identification* of features and content represented within the map; and
3) the *discrimination* of adjacent mapped features in order to determine broader patterns and scene arrangements.

Non-visual perception is also susceptible to confusion as a result of illusory effects or physiological limitations (Gentaz and Hatwell 2008, Pielot et al. 2007).

The detection phase of perception begins when sense organs are triggered by encountered stimuli, such as when a finger is pressed against a tactile map or sound reaches the ear. For a percipient to detect map features the type, magnitude and quality of stimuli must match their sensory capacities. Understanding the perceptual parameters that define which stimuli non-sighted people can best detect tailor maps and computer mapping interface formats to users' unique sensory capacities. Technical research about perceptual mechanisms typically focuses on neurophysiological and psychophysiological traits (Jehoel 2008). The former seeks to understand how and why different stimuli trigger mechanoreceptors to alert the brain about its surroundings while the latter seeks to understand the upper and lower limits for discernable sensations as well as thresholds of acuity, such as the smallest perceivable differences between stimuli.

The sensory aperture of the sense organ used to detect information mediates the volume and scale of invariants that can be perceived at any given time (Klatzky et al. 1993b). Sensory aperture is akin to the visual concept of field of view, which describes the extent of a scene that can be visually observed (Loomis, Klatzky and Lederman 1991). The ears, eyes and tongue have high capacity sensory apertures and can detect and attend to many different invariants at once, while other sense organs, like the skin, become easily confused when presented with multiple invariants. Vision and audition are recognized for providing highly precise spatial and temporal information and the haptic system is more effective at processing the material characteristics of surfaces and objects. (Lederman and Klatzky 2009)

Studies report that a larger sensory aperture does not always result in more efficient perception. For instance, while bi-manual exploration yields better results that uni-manual exploration of tactile and haptic scenes, exploring diagrams using two or more fingers on the same hand does not offer significant improvements over one fingered exploration (Loomis et al. 1991, Jansson and Monaci 2003, Ballesteros, Manga and Reales 1997). Understanding the limitations and capacities of each sensory channel is, therefore, necessary when creating multi-modal geographic representations. Because non-visual sense organs have relatively constrained sensory apertures compared to the eyes, it is likely that non-visual maps must contain correspondingly simpler and less dense information.

Stimuli identification enables the recognition of detected map features. Identifying mapped information involves comparing any detected invariants to known prior examples. Some representative map features, such as those created by virtual reality systems, are thought to be innately identifiable if they consistently recreate the sensations provided by authentic phenomena. Abstract symbols and unfamiliar invariant representations must be learned however. In most visual maps, a legend of labelled reference examples is provided to facilitate the identification of features via matching. An equivalent legend or query system must be provided in non-visual systems to facilitate feature identification as well.

Discriminating map content involves determining which features identified on a map differ and in what ways. Research in this vein studies the body’s ability to distinguish discrete items from adjacent features and the background map. It is important, therefore, to define how much two objects can differ in order to not be considered the same and much research has attempted to standardize and refine symbol properties and representational patterns for this reason. Caduff and Timpf (2008) assert that salience of each feature identified within a map contributes to its distinguishability. Salience denotes a quality of being distinct, prominent or obvious relative to other features. It is a unique property derived from the trilateral relationship between observer, referenced spatial feature and the physical environment.

3.4.2 Exploration:

Map exploration research in non-visual cartography examines the efficiency and effects of various procedures used to search for the information represented in non visual maps. The map exploration strategies of non-sighted and sighted people differ due to their dissimilar perceptual paradigms. Non-visual maps, particularly tactile and haptic maps, are generally perceived and explored serially by hand, rather than synoptically via the eyes or other sense organs (Perkins and Gardiner 2003). Given that, this area of research is most commonly concerned with hand movements used to facilitate the perception of tactile and haptic maps, but also investigates listening habits and other sensory tendencies to a lesser extent. Exploratory hand movements that are categorically similar may be divided into stereotypical patterns, each of which reveals spatial data in a different way. Understanding how the field of a map is revealed by certain exploration patterns is important as the path of serial exploration determines whether features are found, missed, distorted or re-explored but interpreted as new.

When serial modes of perception are used to explore a scene, some organization strategy must be employed to determine and organize the spatial relationships between detected features and transpose these perceptions into a cohesive scene. Many researchers believe that the scanning patterns and strategies used to explore a tactile scene affects this process of transposition and that some may facilitate synoptic understanding better than others. If hand movements are employed to seek out information represented within a map, they are said to be purposeful; they are intended to find certain elements from a map that are desired by a user (Lederman and Klatzky 1996). Simultaneous or sequentially performed exploratory procedures allow percipients to integrate unique properties about the identity of multi-attribute objects and reach deeper reflex levels of perception. Various exploration patterns have different costs and benefits (Lederman and Klatzky 2009) and each one reveals a different type of knowledge about an object or map being observed without sight (Figure 3.11)

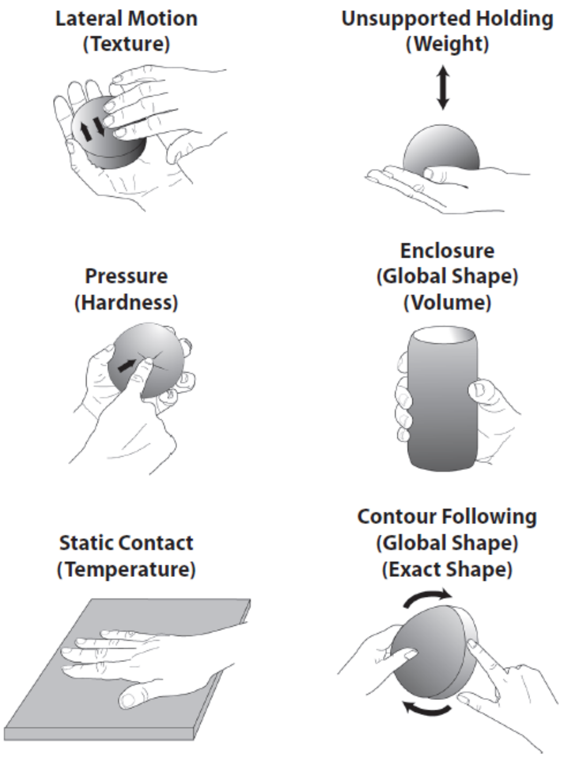

Figure 3.11 Haptic exploration procedures for tangible objects. (Lederman & Klatzky 2009)

Exploration procedures also help link perceived geographic data to mental spatial schemas that are developed from human experiences with their environment (Sluter 2001). Several schemas are used as frameworks for the internalization and exploration of cartographic representations, such as containers, neighbours, and part-whole relationships; up-down, front-back and adjacency relationships; links; center-periphery gradients; source-path goals; and linear sequences or orders(Sluter 2001). Power (2008) documents a number of stereotypical hand movement exploration procedures that can be used with tactile and haptic maps to identify different spatial schemata. These include perimeter, grid, object to object, perimeter to object, home location to object, predefined path, and cyclic search patterns (Figure 3.12). Understanding the associated spectrums of map schemata and exploration procedures can help cartographers make better design decisions since these frameworks dictate where users will expect to find certain types of information and how they will go about finding it. However, little research has been completed to identify differences between the embodied image schematas of sighted and non-sighted people.

Various patterns have been compared, contrasted and tested to find the best techniques or patterns for reading tactile maps, but contradictory assertions are often made. For this reason, Perkins and Gardiner (2003) suggest that it is important to place the reading process within the wider context of map reading to ascertain how, when and where the map is used and who is using it, as these are factors that will ultimately affect the reading pattern. Furthermore, exploration procedures are known to have inherent strengths and weaknesses (Lederman and Klatzky 2009) so it is likely that certain map designs are better suited to some exploration procedures more than others.

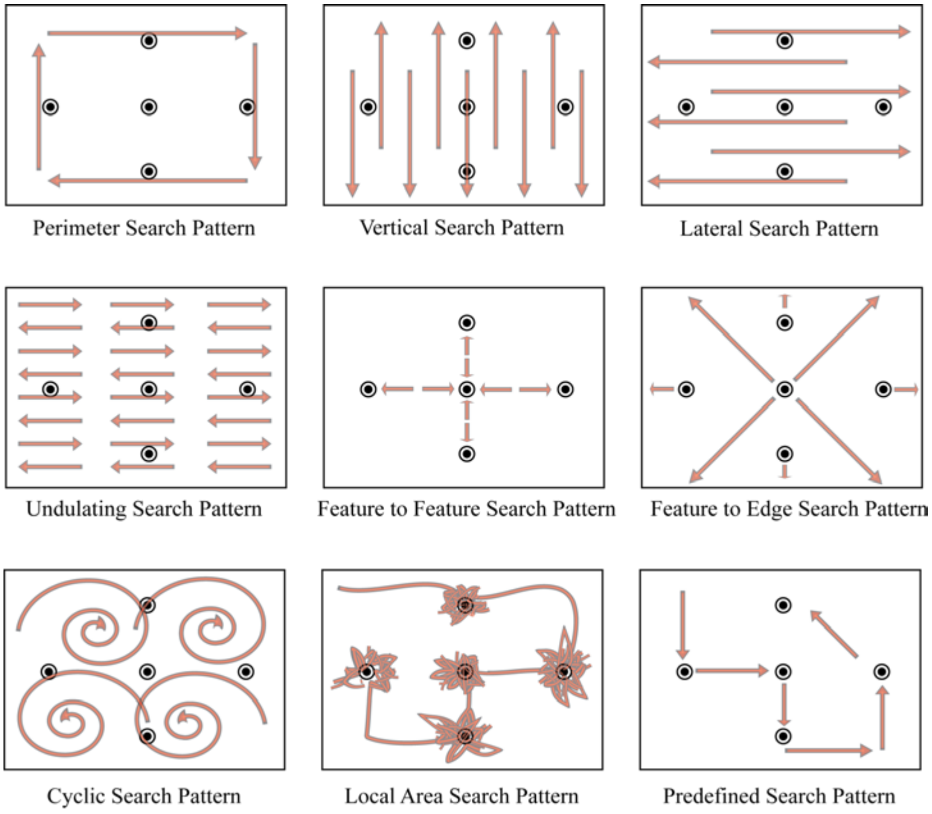

Figure 3.12 Noted tactile map exploration strategies of blind and visually impaired users. Adapted from Power (2008).

In his study of blind students' capacities for shape recognition using tactual distinctive feature analysis, Berla (1977) made three striking observations. The first was that many of the children participating in his shape learning experiments failed to fully explore the content presented.

Second, most students did not have a systematic method for exploring shapes. Finally, some students had difficulty recognizing what points on the shape had been explored and where the start and end points of the shape were located. Without a synoptic form of perception, alternate strategies are necessary to create a mental structure upon which to organize, arrange and process perceived stimuli.

Lederman and Klatzky (1987, 1993a, 1987, 1993, 2009) make several key points regarding haptic perception. They note that traditional models of visual object recognition are inappropriate for haptics because they generally emphasize the importance of spatially aligned edges, which the haptic system extracts poorly. Also, when exploration is not temporally constrained, material properties are more salient than geometric properties. This contrasts with visually assisted exploration wherein geometric properties such as 2D and 3D shape are more salient for object recognition and grouping. These findings suggest that spatial information encoded for non-visual representation should focus on the use of material properties as the primary mode of encoding, rather than shape or area.

Exploration also varies between immersive and non-immersive representations of geography. Non-immersive representations, which support an external perspective, must be actively explored to reveal their information. Immersive or virtual reality representations impose information directly on the user and thus include passive forms of exploration. Hearing ambient sounds or being touched tends to focus the observers attention on his or her subjective bodily sensations whereas active exploration tends to guide the observers attention to properties of the external environment (Lederman and Klatzky 2009).

3.4.3 Cognition:

There are two general themes of inquiry in the cognitive stream of research in non-visual cartography: spatial cognition and cognitive mapping. Spatial cognition concerns how mental mechanisms achieve the consumption and digestion of external stimuli from or about an environment. Cognitive mapping is an abstraction and concerns how the mind prepares a mental reconstruction of the geographic information.

Downs and Stea (1977) describe cognitive mapping as "a process that is composed of a series of psychological transformations by which an individual acquires, codes, stores, recalls and decodes information about the relative locations and attributes of phenomena in their everyday spatial environment. (p. 9)" Map use can support cognitive mapping[10] by providing an alternate source of information about the spatial world. Research concerning the physiological and psychological processes that contribute to the creation of cognitive maps is inconclusive as yet, but the effect and function of cognitive maps is better understood.

Cognitive maps allow individuals to learn about landscapes and develop mental models of the world they encounter. These models facilitate spatial problem solving by providing procedural knowledge and survey knowledge.

Cognitive maps may also embody abstract elements such as emotional impressions of space, contextual characteristics and conceptual associations. For example, cognitive mapping can help individuals define where significant places like 'home' or 'work' are in relationship to each other. It may also establish territories that feel safe, unsafe, stimulating, dull, romantic, stimulating, or productive. Or cognitive mapping may conceptually link locations and places to historical events, memories, or future possibilities, such as planning activities.

The construction of mental models through cognitive mapping involves many processes. The geographic framework created by Lynch (1960) asserts that paths, edges, nodes, landmarks and districts are key elements of cognitive maps. When exploring a space, or representation of space, perceived features can be filtered into these categories. Any map that is serviceable for sighted or

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[10] Cognitive mapping is associated with many other tasks beyond spatial awareness, such as concept mapping, process mapping, semantic mapping, etc. Only those cognitive mapping concepts related to spatial understanding will be discussed here.

non-sighted users must be able to clearly represent these components and afford interactions that allow the creation of spatial knowledge through secondary interactions.

The process of developing a cognitive map or mental model of a geographic region necessarily involves integrating disparate collections of information regarding the distribution of features into a larger cohesive whole. Map learners who become familiar with small portions of an environment individually and serially create patches of spatial awareness (referred to as local charts). As exploration continues, the scope of an individual's mental model expands with the addition of new features in their spatial awareness. When immediately adjacent areas are explored, the growth of a mental model is contiguous in that it encompasses increasingly larger areas. However, when representations of disjoined areas are explored separate localized patches of spatial awareness are formed. Yoshino (1991) suggests that a manifold model develops from sets of local charts that each provide mental models for different areas. A manifold model is akin to the collected pieces of a patchwork quilt that have not yet been joined together. Local charts exist within a larger global framework that supports the spatial and hierarchical organization of perceived and explored information. (Figure 3.13) As local charts grow and connect a unified mental model is eventually formed. Any map that is serviceable to sighted or non-sighted users must, therefore, facilitate the unification of mental models by providing a framework that clearly places and connects represented information within a larger context.

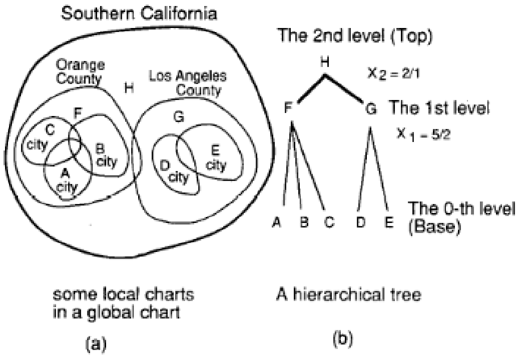

Figure 3.13 Generalized illustration of Yoshino's (1991) local chart structure.

Much of the research related to cognitive mapping emphasizes perceptual and exploration processes related to the initial stage of information uptake. Further research is needed, however, regarding the use of secondary interactions to refine mental models as they are developed.

3.5 Gaps and Suggested Research

One significant area that must still be integrated into the domain of study of non-visual cartography is the infrastructure that will be required to support and maintain non-visual maps. Given that the currency and reliability of spatial information is of the utmost importance for non-sighted people, who lack a significant facility for independent information verification, a concerted effort will be required to create the physical and institutional infrastructure adequate for these tasks. Many questions remain unasked and unanswered in this light. Who will do these jobs? How will they be done? How will non-sighted individuals be involved to ensure their own needs are met?

In particular areas of this domain seeds have been planted for promising future research but have not yet been cultivated and driven to maturity. **Sensuous geography** and a concern for alternative sensory modalities is one such area. Rodaway (1994) explores the nature of geography in relation to the gamut of human senses and attempts to critically explore alternatives to visual primacy in geography. Despite his inspired and thorough discussion, a greater concern for the issues of data collection and data representation in non-visual modalities, beyond touch and hearing, has not yet emerged. Less geographically attended senses related to smell, taste, temperature, pressure and so on may yet prove to be valuable components of spatial awareness. However, suitable methods of data collection and representation for these sensory modalities will be required to integrate them as functional mapping components.

3.6 Conclusion

By surveying relevant literature collections, publications and findings concerning multimodal spatial data access strategies, the third chapter of this thesis has provided a comprehensive review of the existing research foundations for non-visual cartography. Many promising areas for map advancement and future research progress have been identified. These areas include new perspectives on the needs and umwelts of non-sighted spatial data users, instances where ineffective technologies can be replaced by new innovations, and new understandings of the interactive relationships formed between a computer interface and its user.

The emphasis on empirical experimentation, information communication and geovisualization in non-visual cartography has contributed to a profusion of research oriented towards establishing heuristics and guidelines. The central intent of developing cartographic guidelines is to allow future researchers to avoid repeating problems other have encountered already. Heuristics produced in this manner embody the filtered and condensed knowledge gained during previous map development and testing procedures. However, by adhering to these guidelines new researchers become bound to the approaches of the past if they do not critically assess their meaning. A number of key findings can be taken from the review of non-visual cartography research provided in this chapter that will inform the next steps of this investigation. These findings are intended to identify new opportunities for divergence from the status quo of non-visual cartographic research and illustrate where new directions exist to search for novel spatial data portrayal strategies.

The first key finding of note is that despite a wealth of attempts no tested device, platform or strategy has yet been able to fully meet the needs of blind and visually impaired users. This reaffirms the existence of large gaps in this area of research and outstanding problems that need to be resolved. New innovative technologies and approaches to map making still remain to be devised to overcome the issues that are currently inhibiting progress in this field.

It is also worth noting that no multimodal map rendering method or technology can be truly successful if it is developed in isolation. No matter how powerful the intended technological fix for a given problem may be there are always ancillary factors that must be addressed to create a useful spatial data platform. For instance, a novel data display device is of no use if there is no content to explore and no infrastructure installed to create and share new data scenes. Without these complementary supports, the innate utility of a device becomes largely irrelevant and so a very comprehensive and holistic approach for the provision of non-visual cartographic services is absolutely essential. It is simply not enough to meet one or a select few of a user's specific needs, every critical element must be present to ensure the serviceable multimodal spatial data access. In this context, the chain of affordances supporting non visual data access is only ever as strong as the weakest link.

To determine which critical user needs and affordances must be addressed by an accessible multimodal spatial data platform a brief interface requirements engineering study was completed, the results of which are presented chapter four. This study built upon the key findings, heuristics, and design guidelines documented here in order to prepare a framework of interface design specifications that were employed to develop a new interface prototype, which is presented in chapter five.

4 Modeling Ideal Maps

4.1 Introduction

The stated intent of this thesis is to investigate potential approaches for creating maps that are both accessible to non-sighted people and functionally equivalent to traditional visual maps. While this purpose is clear enough, the sub-goals that must be addressed to achieve it present many complicated conceptual issues. Developing a platform that can present geographic information to non-sighted users is a core sub-goal of this pursuit. For approaches that recommend that map access be facilitated by computers the design parameters of all new proposed systems should be defined before development and production begin. However, this is not an ad hoc task. Brooks (1995) emphasizes the vital importance of pre-emptive design refinement by stating:

> "The hardest part of building [an information system] is deciding precisely what to build. No other part of the conceptual work is as difficult as establishing the detailed technical requirements, including all of the interfaces to people, to machines, and to other software systems. No other part of the work so cripples the resulting system if done wrong. No other part is more difficult to rectify later. (p. 86)"

Many computer systems and devices designed to provide non-visual map access have been crippled by inadequate attention to design requirements. It is critical to identify from the outset what characteristics and affordances an information system must include in order to be of value to its users. It is important to recognize that the barriers non-sighted people actually face differ significantly from sighted technology designers' expectations. Shinohara and Tenenberg (2009) reflect on the impact of this by stating that "Without careful considerations for the limitations in usability and the meaning of the interactions affecting blind users, sighted technology designers may unwittingly create interfaces with the wrong affordances, that are dissonant with users personal preferences, resulting in task failure" (p. 59).

Any useful tool, be it a computer, a map, or a compass, should help its user overcome the barriers or limitations that prevent them from carrying out a task unassisted. The barriers faced by non-sighted people can be classified in two categories: structural barriers and functional barriers (Marston and Golledge 2000, Marston and Church 2005). Structural barriers are impediments that result from a disconnect between an individual’s abilities and the physical design of their tools or surrounding environment. For instance, a wheel chair cannot travel up stairs. Glasses that are the wrong prescription will not improve a wearer’s sight even though they are the correct tool for the task. A non-sighted person will not be able to perceive visual stimuli, such as printed text or diagrams, no matter how much they practice. Functional barriers, however, result from an object’s mode of operation rather than its form. For instance, an assistive device that speaks in a foreign language presents a functional barrier against use. A ruler that is marked in inches cannot be used to measure centimetres. Likewise, a computer system that is difficult to assemble and learn to use presents a functional barrier to the user even if it can perform many powerful computing tasks. Addressing these issues requires concern for both physical and operational design characteristics.

Completing a Requirements Engineering Analysis [REA] is a procedure that is often used in industrial and software design to develop and refine the fundamental traits an information system must possess (Westfall 2006). The Requirements Engineering process starts with building familiarity with the intended users’ needs and challenges. The next step after identifying the users’ needs is to determine the role and nature of the system being designed, in terms of its optimal form and how it must operate.

This chapter provides a basic REA for non-visual GIS. The findings discussed in chapters two and three concerning previous research efforts in non-visual cartography were used in this analysis to complement published summaries of user needs. These findings will be supported by guidelines and heuristics produced from technical investigations and alternate study areas in non-visual cartography. A list of desirable traits for non-visual GISs was created as an output of this REA. It addresses traits related to form (i.e. how a system must be designed to avoid structural barriers), operation (i.e. how a system must be designed to avoid functional barriers), and affordance (i.e. how a system must be designed to meet its users’ needs). These findings were then used to guide the design of the prototype non-visual GIS described in chapter Five.

4.2 Requirements Engineering Frameworks

Pohl (1994) suggests that a fundamental rationale or perspective framework must drive the requirements engineering process in order to elicit and capture various design criteria. The Interactionally Rich Systems [IRS] framework will be used as a primary basis for the requirements engineering process in this chapter. This framework has been developed by the Interactionally Rich Systems Group, which is a cooperative network of information technology researchers. Their investigative motivations address the benefits arising from the increasingly wide range of available input and output devices for computers (Duce 1997). Their cooperative research efforts have attempted to build a deeper understanding for the ways in which information systems may embody ‘richness’.

Various dimensions are associated with the quality of richness. Richness, in this context, is the sense that “leverage and flexibility in interactive, conjoint, behaviour between user and computer, may be achieved in some minimal way” (Duce 1997) (p. 163). Device flexibility, versatility, and interaction synergy are three central dimensions of this quality. Flexibility allows users to achieve the same result in several ways and offers multiple methods for overcoming a particular barrier. Versatility reflects the range of tasks that a system can effectively perform and speaks to the value of a system in a multitude of different contexts and scenarios. Interaction synergy reflects the character of the interactions realized between a computer and user in terms of the qualities of an interaction experience (e.g. good, poor, fun, pleasant, tiring, confusing, frustrating, efficient, tedious, etc.). Once destructive and desirable qualities within this dimension are identified, their root causes can be mitigated or enhanced to improve the system.

Duce (1997) suggests that the number of actions an instrument can perform, or the amount of behaviours that it affords its users, can be considered a measure of its richness. For example, a knife and a pen are both extremely simple yet versatile devices that can, in the hands of a skilled craftsman, become highly flexible and productive tools. A map, or computer based GIS, could similarly be placed in this category of systems of versatile tools. The IRS approach emphasizes the goal of creating ‘human-centered’ systems as a key direction forward to develop an increased synergy between human users and computer systems .

Human-centered systems fully respect six general design characteristics:

- They take into account human and perceptual motor capabilities and limitations;
- They support actual practice (real behaviour in real tasks) effectively;
- They are flexible rather than rigid – that is, they can be used in many ways and do not unnecessarily constrain users;
- They are context sensitive and adapt to users' changing needs;
- They are open and inspectable so that users can understand them;
- They are engaging and enjoyable.

Design requirements and criteria for non-visual maps and GISs that are identified through the requirements engineering process will be classified within these six categories.

The guidelines for barrier free universal product usability produced by the Universal Design Center at North Carolina State University will also inform this requirements engineering process. Vanderheiden (2000) defines universal usability as "a focus on designing products so that they are usable by the widest range of people operating in the widest range of situations as is commercially practical." (p.32) Universal design, and derivatives such as Design for All (Aslaksen et al. 1997) , Universal Design for Learning (Hall, Meyer and Strangman , Hitchcock and Stahl 2003) and Universal Design in Education (Bowe 2000), focus on seven key areas. These areas are:

- Equitable Use
- Flexibility in use
- Simple and intuitive use
- Perceptible information
- Tolerance for error
- Low physical effort
- Size and space for approach and use

These principles serve to ensure equitable access when a diverse array of user needs must be accommodated, such as is the case within the non-sighted population and when sighted and non-sighted individuals collaborate. Additionally, Alonso et al. (2008) note that there are a number of specific usability dimensions for the development of user interface models for non-sighted people, which include:

- *Task adequacy*: the task has to be adequate to the given capabilities of a non-sighted user;
- *Dimensional Trade-off:* the user interface has to provide a balance between the 2D access of sighted people and the 1D access of blind people;
- *Behaviour equivalence:* the user interface has to provide specific access for blind people to all the relevant user interface objects;
- *Semantic Loss avoidance:* the user interface has to avoid losing relevant semantic information;
- *Device Independency:* the platform developed for non-visual map access should not be dependent on any particular operating system or computer brand.

Drawing on these premises allows an index of desired traits for non-visual maps and GISs to be developed (Table 4-1).

Take into account users' physiological capacities and limitations	4.3.1.1 - Utilize all viable interaction channels and modality combinations 4.3.1.2 - Avoid body constraints 4.3.1.3 - Maintain appropriate interface-body proportions 4.3.1.4 - Minimize fatigue 4.3.1.5 - Maximize direct sensory engagement 4.3.1.6 - Manage sensory illusions 4.3.1.7 - Manage map complexity
Emphasize system flexibility rather than rigidity	4.3.2.1 - Provide Dynamic Representations 4.3.2.2 - Utilize hypermedia premises 4.3.2.3 - Utilize virtual properties where possible 4.3.2.4 - Utilize both material and geometric representation formats 4.3.2.5 - Support multiple map exploration strategies 4.3.2.6 - Provide users with comprehensive configuration options 4.3.2.7 - Employ Redundancy
Support actual practice through efficient and functional use	4.3.3.1 - Employ functional separation to minimize cognitive load 4.3.3.2 - Provide intuitive interactions 4.3.3.3 - Facilitate smooth and refined operation 4.3.3.4 - Provide constant feedback and maintain synchresis 4.3.3.5 - Provide Memory Aids 4.3.3.6 - Create constraints where necessary
Emphasize context sensitivity and adapt to users changing needs	4.3.4.1 - Emphasize easily updateable and distributable spatial information 4.3.4.2 - Support a wide spectrum of uses 4.3.4.3 - Create Growable systems 4.3.4.4 - Emphasize portability
Create open and inspectable computer systems	4.3.5.1 - Integrate tangible/analog components 4.3.5.2 - Respect established standards 4.3.5.3 - Label Everything 4.3.5.4 - Provide complete and accessible documentation 4.3.5.5 - Emphasize design consistency throughout the system 4.3.5.6 - Always provide contextual information 4.3.5.7 - Provide well defined points of reference
Create engaging and enjoyable non-visual geographic information systems	4.3.6.1 - Provide Pleasant Sensations 4.3.6.2 - Maintain compliant representations and semantic fidelity 4.3.6.3 - Support inconspicuous operation 4.3.6.4 - Make systems easy to setup, activate and maintain 4.3.6.5 - Ensure enjoyable and fun operation 4.3.6.6 - Provide training exercises 4.3.6.7 - Provide assistance agents

Table 4-1 Affordances required for accessible and useful multi-modal spatial data platforms.

4.3 Guidelines

4.3.1 Take into account users' physiological capacities and limitations

4.3.1.1 Utilize all viable interaction channels and modality combinations

Multimodal interfaces are said to be ideal for facilitating universal access to digital information (Oviatt et al. 2004). Interfaces of this sort provide many advancements for spatial information access (Golledge, Rice and Jacobson 2006) and facilitate increased possibilities for effective data representation and interpretation (Jacobson 2002). Integrating multiple interaction modalities in GISs allows individuals to access information in ways that are appropriate to their unique physiological abilities, sensory capacities and preferences. This helps overcome both structural and functional barriers by creating input and output opportunities that match individual physiological capacities and working styles.

Oviatt (2006b) suggests that every person has unique integration patterns, which are tendencies of reliance towards particular modalities when performing a task. Maximizing the variety of modalities used in a mapping system increases the number of available sensory channels users may employ to explore data and operate the system. This also allows a wider range of users with differing sensory capacities and integration patterns to use a given system.

Some modal combinations are thought to be mutually beneficial and should be emphasized when possible (Sarter 2006, Reeves et al. 2004a). For instance, augmenting haptic representations with sounds and audio information has been demonstrated to provide better information uptake than either modality could achieve individually (Rassmus-Grohn 2006, Iglesias et al. 2004, Alonso et al. 2006, Belardinelli et al. 2009, Hermann and Ritter 2004). Similarly, other promising modal combinations have been demonstrated, such as haptic and vibrotactile combinations (van Erp 2002) or haptic and thermal combinations (Nam et al. 2005). Oviatt et al. (2003) note that there are many myths regarding integration patterns in human computer interactions and care should be taken to ensure that multimodal interfaces do not create more problems than they solve. GIS operation must not be made more cumbersome by indiscriminately integrating many modes of command and control input within a system. Care must be taken to ensure that the presentation of information via multiple modalities does not overload or confuse the user.

4.3.1.2 Avoid body constraints

Usability issues related to physical impediments, beyond visual impairment, are often incompletely addressed in literature concerning potential non-visual mapping systems. However, structural barriers related to body posture, reach, stability, and movement have a direct impact on mapping experiences and are fundamental concerns for universal design. Bodily constraints and poor ergonomic designs can make GISs difficult, uncomfortable, or even painful to use (Golledge et al. 2006). For this reason, map fields and interface devices should be comfortably shaped and placed within easy reach of the user. This allows for an open body position and prevents over extension, feelings of being cramped or movement barriers.

The construction and orientation of a human-computer interface relative to its user's body has the strongest impact on ergonomics and usability. Any hardware or structural components that a system requires to mount devices overhead, such as tripods and armatures, should be designed so that users will not inadvertently bump them during exploration and hurt themselves or dislodge sensitive equipment. Wherever possible, wireless options should be used to connect peripherals to a control computer so that both users and equipment do not become entangled during use. Similarly, any cords or cables that are absolutely necessary to assemble a non-visual mapping system should be firmly affixed to a stable surface. Alternatively, necessary cables can, in some instances, be used as leads so that objects located beyond a users reach can be easily found. For instance, the cord that connects a pair of headphones can be arranged to lead directly to the power switch of a computer system.

4.3.1.3 Maintain appropriate interface-body proportions

The scale and design of non-visual maps and GISs must be appropriate to the relative body proportions of the intended user. The nature of human physiology imposes certain constraints in terms of reach, natural postures and rotations. These constraints must be respected by human computer interface designs (Benford et al. 2003). The size of a map's field and the scale of plotted content should respect the user's distal reach, range of motion and sensory aperture. Ideally, the size of a non-visual GIS and its field should be scalable relative to its user and task in the same way that a paper map can be folded and unfolded to reveal more or less content. For instance, a small child first learning to use a mapping system may be best served by a relatively small map field, whereas an older or more experienced 'power-user' may wish to maximize their available map real-estate. This is akin to adding a second monitor to a desktop computer to expand the visible screen space. Systems with larger fields, such as interactive tabletops or immersive VR chambers may also facilitate multi-user collaborative activities (Furuichi et al. 2005). Users exploring tactile representations may have smaller or larger than average hands and should be able to scale content to match their proportions.

4.3.1.4 Minimize fatigue

The onset of different forms of user fatigue can severely impair a mapping system's efficiency and success. Types of fatigue related to non-visual map exploration include physical, perceptual and mental fatigue. Physical fatigue can cause muscle discomfort, loss of fine motor control, imbalances and other difficult sensations. Perceptual fatigue can cause poor sensory acuity, localized discomfort, and increased susceptibility to perceptual illusions. Mental fatigue can cause diminished interest, concentration and attention span as well as decreased comprehension rates and recall abilities. Initially avoiding sources of fatigue in these areas and minimizing their impacts through conscientious design strategies can contribute to more effective mapping experiences (Challis 2000). Fatigue can also be avoided by minimizing the length of a mapping session, encouraging habituation, changing representative parameters, tailoring exploratory procedures and providing assistive services.

Ergonomic factors should be considered as a central approach for minimizing user's physical fatigue. Systems that maintain neutral body positions and postural stability, such as seated arrangements or relaxed standing stances, can enhance comfort and user endurance (Eason 1991). Conversely, hunched, leaning or unevenly supported body positions will quickly cause fatigue and impairment. For example, users' arms should not have to cross when exploring information or reach out from the body for long periods of time.

Physical fatigue can also occur if tactile or haptic exploration procedures are overly strenuous to the point of muscle discomfort. This can be caused by an over reliance on fine motor control for precise exploration activities, by broad movements or by overly forceful haptic feedback. Devices that utilize haptic sensations and force-feedback technologies should be able to attenuate the forces applied against a user's body and movements so that intense exertion is not required. Movements needed to operate immersive systems also should not induce dizziness or motion sickness (Hakkinen, Vuori and Paakka 2002). These symptoms have been noted with head mounted displays and wearable VR devices where users turn their head or body frequently to move within or manipulate a virtual environment. Repetitive strain injuries can also occur if certain movements or positions are required too frequently.

4.3.1.5 Maximize direct sensory engagement

The uptake of map information through a sensory channel is heavily impacted by the extent to which that channel is full engaged. In general, the quality and quantity of data perception and information uptake is maximized by enlarging the sensory aperture and decreasing mediating factors between a stimuli source and sensory receptor. Sensory aperture refers to the area or extent of perception that a sense organ achieves, in terms of the volume and distribution of nerves receiving particular stimuli. For instance, exploring an item using an entire hand establishes a larger tactile aperture than exploring with the tip of a single finger (Klatzky et al. 1993b). Sounds that are heard in stereo through both ears engage a larger aural sensory aperture than a sound that can only be heard in a single ear. Ensuring that information is presented and available to the largest possible extent of an individual’s sensory capacity increases the potential that representations of information are perceived completely.

Sensory mediation occurs whenever an intermediate layer exists between the source of a stimuli and a sense organ. The introduction of mediating devices can have a significant impact on sensory uptake. Ensuring that as few mediators as possible exist between a stimuli and sensory receptor is paramount. Mediation changes the quality and quantity of a stimulus by filtering or incompletely transferring invariant properties. For instance, a user who explores a tactile map wearing gloves has less direct sensory engagement than someone without. In some instances, however, the nature of a mediating item may afford new forms of perception that would not otherwise be available. The virtual forces perceived when using a haptic device cannot be experienced without this hardware, even though the effector exists between the source of the stimuli and the user’s sense organs. Ackerman (2009) comments on this circumstance by stating that “to be deprived of the sensibility and flexibility of the hand is frustrating” but “on the other hand, using a tool holds the potential to expand or augment or tactile experience.” (p.3) Use of the white walking cane by non-sighted people is cited as a prime example of augmentative mediation wherein “by virtue of using a cane the person acquires new motor and perceptual skills” (p. 3). Although a white cane may not allow a person to feel certain qualities, such as the temperature of a surface, it does afford alternative ways to probe an environment. Maximizing direct sensory engagement is accomplished by ensuring that the experience a tool affords, by augmenting or expanding natural perception, is the experience most relevant to the information intended for exploration in a non-visual GIS.

4.3.1.6 Manage sensory illusions

Avoiding unintended illusions that distort the content of a map is imperative for successful non-visual mapping systems. Unintended perceptual illusions reduce the accuracy of geographic representations by creating errors in the mind's cognition of sensory input. Diagnostic tests for cognitive map distortions should be used to look for unexpected illusions wherever possible (Kitchin and Jacobson 1997). Various studies indicate that non-visual perceptual illusions can be triggered by certain forms of information representation (Gentaz and Hatwell 2008). While a complete survey of non-visual perceptual illusions may never be accomplished, many specific illusions have been identified. Furthermore, it is not known if or even how many visual illusions may translate into other perceptual modalities.[11] Classic examples of cross-modal geometric illusions include the Muller–Lyer illusion, the Vertical-Horizontal illusion, and the Delbouf illusions (Figure 4.1) (Suzuki and Arashida 1992). Avoiding incorporating known illusions into non-visual maps will do much to improve the quality of geographic knowledge users can synthesize.

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[11] Gentaz and HatwellGentaz, E. & Y. Hatwell. 2008. Haptic Perceptual Illusions. In *Human Haptic Perception: Basics and Applications,* ed. M. Grunwald. Leipzig: Birkhauser Basel. also note that not finding a visual illusion in other modalities is an argument in favour of the use of alternate or redundant modalities in some circumstances. Spatial information that cannot be visually depicted without illusory effects may be much better served by non-visual representation methods for sighted and non-sighted map users alike.

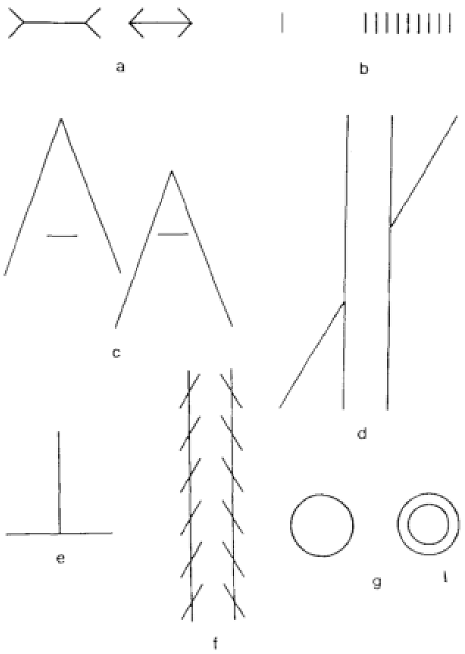

Figure 4.1 Geometrical illusion figures are shown to illustrate potential haptic content configurations that could confuse or mislead non-sighted map users. These illusions, described by Suzuki and Arashida (1992), are the (a) Muller-lyer, (b) Oppel-Kundt, (c) Ponzo, (d) Poggen-Dorff, (e) vertical-horizontal, (f) Zollner, and (g) Delbouf illusions.

In some instances, however, illusory phenomenon can be beneficial. The head-related transfer function (section 3.3.2.3). is one example of an illusion that can be beneficially used to represent spatial information. By adjusting the parameters of sound that are presented through stereo headphones, users can be made to hear sounds from various locations around their body (Rassmus-Grohn 2006). This illusion allows rich and detailed spatial audio environments to be created that virtually recreate foreign geographic phenomena for non-sighted individuals. An alternate example of a beneficial non-visual illusion is the simulation of surface elevation changes in 2-dimensional haptic devices (Lecuyer, Burkhardt and Etienne 2004). By artificially controlling an effector's speed across a surface the illusion of inclined or declined planes can be produced. When the effector slows down, the user feels as though greater effort is required to move uphill against gravity. When the effector regains speed, the user feels as though the surface is now sloped downward and movement is assisted by gravity. Creative uses of illusions such as these may provide new ways to convincingly render spatial information in non-visual modalities.

4.3.1.7 Manage map complexity

Managing the complexity of non-visual GISs can do much to enhance the quality of a mapping experience. Issues of complexity, whether they reflect too much complexity or too little, are generally related to design, operation, and data presentation strategies. If design complexity is not managed then maps and GISs can be difficult to explore, learn and use. Non-visual geographic information systems with elegant or uncomplicated physical designs will be easiest to learn, find, and orient. A balance between functionality and simplicity is required in all cases to avoid providing either too much or not enough of a given factor (e.g. information presented, steps to complete a task, physical points of reference, etc.). Sjostrom (2002) reminds us that complexity does not necessarily imply difficulty in all instances. A known complex object may be more recognizable than an unfamiliar simple object. Furthermore, Jannson and Larsson's (2002) research suggests that while increasing complexity in virtual scenes increases the likelihood of object recognition it also increases exploration time and memory fatigue.

The operational complexity of a computer system can severely affect its functionality. Managing complexity also involves limiting the number of rules that a user must remember (Sjostrom 2002). Burger (1994) states that a minimizing workloads by making operations basic is advantageous. By reducing the number of steps needed to achieve a task the opportunity for errors is reduced and the use of a system will feel less tedious.

If a map's presentation strategy provides too little or too much detail then important information can be hidden or lost. Power (2008) recommends avoiding representations with small scattered surfaces as these can create confusion by introducing overwhelming and possibly indistinguishable amounts of detail into a map scene. Likewise, instances where represented features intersect or overlap should be minimized in order to maintain the discreteness of individual features like roads and paths. A certain amount of complexity is needed to provide contrast between different objects, but this complexity becomes detrimental when overly similar patterns become indistinguishable. The number and type of patterns that are used to differentiate unique categories and symbols on a map should also be managed. McCallum, Ungar and Jehoel's (2006) research found that map users preferred tactile directional symbols that were simple and refined, eschewing those that were overly complex or involved many subcomponents.

4.3.2 Emphasize system flexibility rather than rigidity

4.3.2.1 Provide dynamic representations

Access to information that is variable or constantly changing, as most spatial information does over time, requires a system that can load and render updated data files (Rassmus-Grohn 2006). Mapping systems intended for use by non-sighted people should, therefore, be able to dynamically display a wide variety of spatial content on demand. A fundamental benefit of GISs used by the sighted population is the ability to rapidly and easily access different spatial images and maps from a single computer (Oviatt 1996). In order to achieve equitable provisions for the non-sighted community, the same type of dynamic map access devices must be made available (Bellik and Burger 1995).

Dynamic platforms for map representation provide a way to refresh a map scene to update, alter or animate the presented content. They may also provide a way to depict many different maps with the same display device. Focusing on the production of static maps for non-sighted people will only serve to emphasize the disparity in access to spatial information between the sighted and non-sighted communities.

4.3.2.2 Utilize hypermedia premises

Hypermedia systems relate and connect multiple information files. Independent files referenced in these systems can be accessed by activating links and interactive content embedded in each file. Effectively integrating hypermedia elements into map products can greatly increase the depth of accessible information. Although it is recognized that creating hypermedia content that adequately serves the needs of non-sighted people is particularly difficult, the potential benefits of successful implementation are truly significant (Power 2008, Petrie et al. 1997, Morley et al. 1998).

Hypermedia features support flexible information navigation by allowing users to browse and quickly search through a web of many linked files, as well as within individual pages (Salampasis, Kouroupetroglou and Manitsaris 2005). For instance, hyperlinks embedded within a map can allow users to relocate their focus directly to a particular point of interest without scrolling or panning to search for it. Providing users with the ability to create new hypermedia links or bookmarks, that directly reference internal and external content from a map can automate repetitive tasks to enhance exploration efficiency and decrease cognitive demands (Petrie et al. 1997, Power 2008).

Hypermedia features also enable a greater depth of information by providing enhanced and augmented content. For example, if the symbol or shape used to represent a map feature, such as a city or town, is designated as a hyperlink then activating that link could load an enlarged map of the town or call up additional details like population data, historical facts, major industries, etc. Hypermedia systems also support query tools such as search engines and content filters that can locate desired information from a large body of data. This type of functionality is especially beneficial as it changes the computer from a simple tool that allows the user to hunt and seek for information to a powerful partner that can find information on a user's behalf (Beaudouin-Lafon 2004). Scripts that record the sequences of links a user has activated and provide them for easy recall in a history tool provide similar assistive benefits (Morley et al. 1998).

4.3.2.3 Utilize virtual properties where possible

When creating computerized maps, particularly in immersive or partially immersive formats, many augmentations of spatial reality can be employed. While it is important to ensure that representations of spatial data are meaningful to the user and that semantic fidelity is always maintained, verisimilitude and absolute authenticity are not always necessary. Making use of opportunities to integrate virtual properties into computerized map representations can be a great benefit (Sjostrom 2002).

Nearly any property in a virtual scene can be manipulated to increase its salience. For instance, slight elevation changes across a landscape can be virtually exaggerated to make an attribute more apparent (Figure 4.2). Inanimate objects can also be animated and made to move, vibrate, pulse, float, bend, etc. Normally unattractive objects can be given magnetic properties in virtual reality scenes in order to attract the user's effector as it passes nearby. Sound events that would quickly decay to an imperceptible volume in the real world can be extended or repeated in a continuous loop to improve perceptibility in a computerized map (Hermann and Ritter 2004).

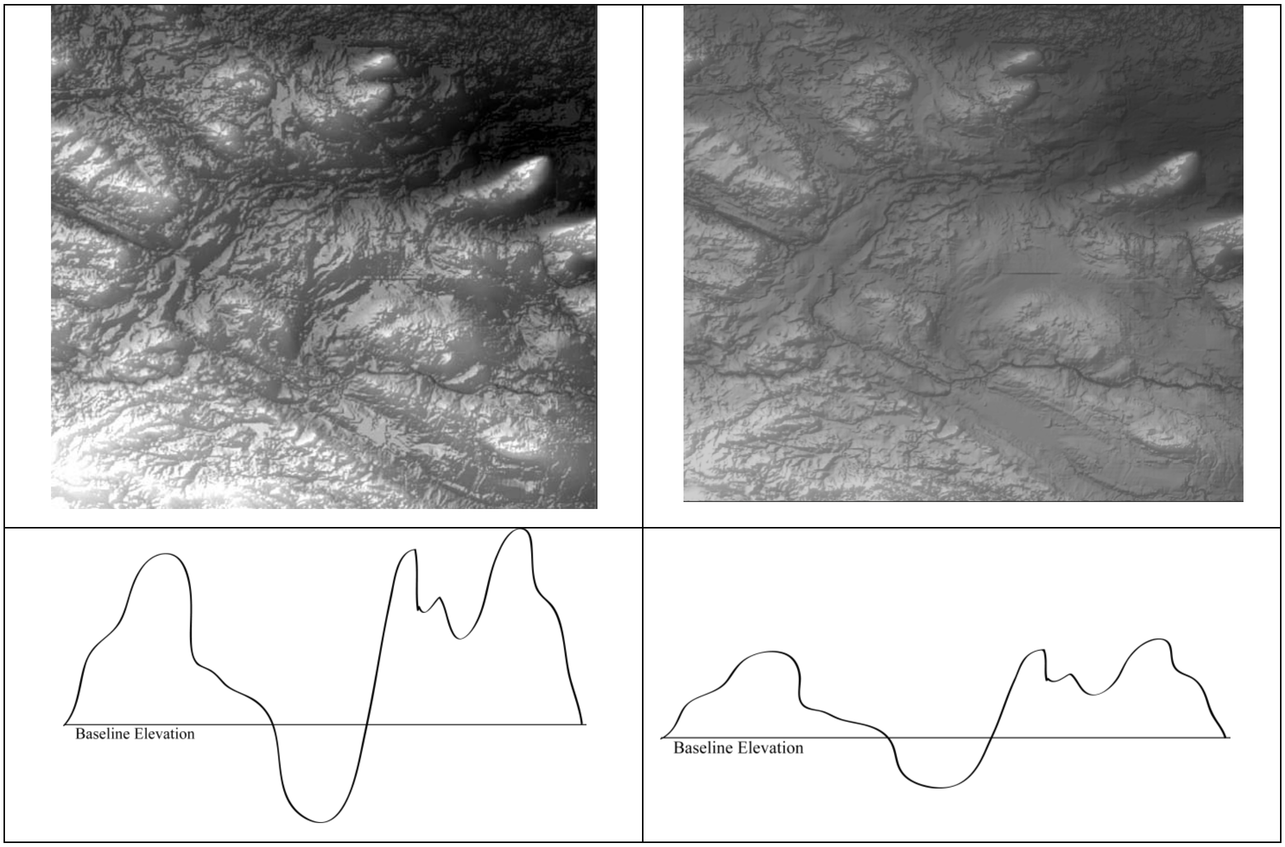

Figure 4.2 Virtual exaggeration is used to create stronger differentiation in topographic profiles. Slopes shown in the left image have appear steeper and taller than those on the right in order to emphasize minor elevation changes, even though both images were produce from the same dataset (NRC 2002a).

4.3.2.4 Utilize both material and geometric representation formats

Non-visual maps and GISs should be enabled to convey both material and geometric properties for representative spatial objects. The types of invariants that a map can produce defines the type of information it can represent, thus limiting the available categories of invariants that can be reproduced also limits the information that can be represented. A map that can only provide cues about the type of object being examined without revealing its shape, size or form presents many difficulties. Material invariants, such as texture, temperature, scent, surface compliance and malleability, and magnetism or repellence are excellent for conveying categorical attribute data about geographic features, but do not easily reveal spatial arrangements. Many maps that can only offer serial modes of exploration, such as mouse-over style audio maps, are troubled by this issue. Users are provided with sounds that indicate certain regional thematic qualities found at the location of the cursor within the map, such as nationality, language spoken, GDP, etc, but little information is provided to delineate the layout of these adjacent regions.

Likewise, maps that can convey the layout and geometric pattern of regions across a surface but cannot easily differentiate each discrete region with a unique material identifier, such as many static tactile maps, are equally troublesome. Geometric invariants, such as edges and shape boundaries, elevation changes, and line angles or curves are excellent for describing spatial arrangements but do not easily convey thematic or categorical spatial attributes, even if bi-manual exploration is possible. Perceptual difficulties often conflict with the use of geometric properties to represent geographic classifications. For instance, Rice, Jacobson and Golledge (2005a) note that map users can easily count the number of corners of a simple shape, such as a square or triangle, but often have difficulty differentiating proportions between similar objects like squares and rectangles or circles and ovals.

Over reliance on either type of cartographic property can detract from the quality of a map and can force the use of less desirable cartographic conventions (Hill et al. 1993). For instance, Sjostrom (2002) suggests avoiding differentiating symbols by geometric properties (i.e. five vs. six vs. seven sided figures), especially when similar shapes given different material textures or profiles could be more effective (Dinar et al. 2005). Perceptual illusions are also more prevalent in geometric figures (Suzuki and Arashida 1992) so an over reliance on this type of cartographic element may result in a greater likelihood of cognitive map distortions.

4.3.2.5 Support multiple map exploration strategies

Allowing users to chose and carry out a variety of different map exploration strategies according to their personal preferences and intended task is vital for universal accessibility. Hill et al. (1993) highlight a sequence of five key sub-goals that must be carried out when non-sighted people explore novel spaces and map scenes: 1) Exploration objectives must be established; 2) A suitable starting point must be established; 3) A systematic search pattern appropriate for the objective must be selected; 4) A method for implementing the systematic search pattern must be determined; and 5) intermediate search strategies that develop object to object relationships from features that are discovered must be established. Differences within each sub-goal can alter the nature of the exploration strategy that must be used to explore a map. Thus, support for each of the resulting strategies must be provided by a nv-GIS if all user needs and overall objectives are to be met.

Support for different map exploration strategies can be provided in many ways. Operation modes tailored for exploration strategies that require unique feedback information and/or points of reference can be prepared for computerized GISs. For instance, users who wish to explore a tactile or haptic map field using a lateral side-to-side pattern could set the system to provide feedback, such as a sound clip or vibration, when the longitudinal midpoint of the map has been crossed. Alternatively, users who are exploring the spatial audio landscape of a 3D VR scene could select to hear all nearby sounds at once in an ambient audio collage or they could explore only sounds within a certain distance andor relative angle from their location. Training exercises and guidance programs that teach different exploration procedures can also be provided to support multiple exploration strategies (Berla and Butterfield 1977, Feygin, Keehner and Tendick 2002).

4.3.2.6 Provide users with comprehensive configuration options

To ensure that a mapping system can meet its users' needs and preferences exactly complete configuration control over operating parameters should be provided. Human centered design premises call for systems that flexibly adapt to their users' needs and preferences. The ability to select and modify parameters and variables within a human computer interface is common in designs intended for sighted users and can do much to increase a user's comfort, familiarity and acceptance with a particular system. Reeves et al. (2004b) note that a multimodal interface should be adaptable to its user's needs and abilities as well as different use contexts and objectives. These authors also note that the ability to define a personalized settings profile for unique users may also be useful in contexts where many people access or use a single computer system.

Many different representative and operational parameters may be made configurable for multi-modal non-visual GISs. These parameters include operating speed, tone, volume, pitch, rate of playback, panning and zooming intervals, reference units, keyboard shortcuts, voice commands, device sensitivity, and force feedback strength. Screen readers that synthesize human speech provide an excellent example of the possibilities for configuration control. Research by Nass and Lee (2001) found that users of synthesized speech interfaces prefer voices that are most like their own. They assert that providing configurability for synthesized speech characteristics, such as speed, intonation, and frequency range, is very important as it allows users to select voices that are consistent with their own socialization and personality. This eases adaptation and builds trust when interacting with the computer system.

4.3.2.7 Employ redundancy

Ensuring the provision of redundancy is a fundamental premise of universal design and human-centered systems. Providing redundancy in the input, operation and output of a non-visual mapping system will create a more flexible, fault tolerant, effective and responsive system. The variety of offerings integrated into a redundant system serve to augment, complement and enhance one another. There are three main advantages of employing redundancy in multi-modal GISs (Wickens and Baker 1995). The first advantage is that the information flow between a computer and user is less vulnerable to a user's errant attention shifts. Secondly, demonstrably higher rates of memory retention are possible when information representations are presented through different channels. Finally, when information is presented through many different modalities users are able to rely on the preferential mode of exchange that they have the best sensory access to or that best suits their personal integration pattern. Additionally, redundancy can be used to create systems that are more tolerant of user and system errors (Barbour and Wojcik 1989). For instance, haptic and VR systems that rely on multiple sensors will be much less likely to lose track of or miss subtle body movements during map explorations.

Jacobson (2002) notes that redundancy is not akin to pure repetition. Designs that embrace redundancy offer the user a variety of different yet parallel channels and opportunities for interaction oriented towards the same purpose (Golledge et al. 2006), whereas repetitive systems offer multiple instances of a single modal interaction opportunity with no variation. In a redundant system map features can be labelled using printed text in many languages, Braille lettering and sound cues, while a repetitive system may only include extra superfluous text labels varied only by font or text size. Explicit commands can also be input into a multi-modal computer system in many different ways. For instance, a keyboard shortcut can be typed, a voice command can be spoken, a multi-touch gesture can be made on a touch sensitive surface, a mouse can be clicked and so on, each achieving the same end.

4.3.3 Support actual practice through efficient and functional use

4.3.3.1 Minimize cognitive load

Minimizing the cognitive load placed on users of non-visual GISs is critical in supporting successful and efficient mapping activities. Well designed computer systems achieve this with more sophisticated interaction strategies as well as by actively assisting the user's activities.

Marcus and Van Dam (1991) suggest that the challenge for designers of next generation user interfaces is to create novel devices and new means for system navigation, command and control, and data representation that lighten rather than increase users' cognitive loads. Oviatt et al. (2004b) have found that users respond to changes in their cognitive load by shifting to available multi-modal interactions as mental demands increase with task difficulty or complexity. Determining natural, intuitive associations between tasks and/or information types and interaction modalities is a critical step in improving multi-modal interface design (Sarter 2006).

Beaudouin-Lafon (2004) asserts that computers may serve as partners for their users in many contexts. Allowing computer programs to perform tasks on a user's behalf and carry certain burdens can be very beneficial. Integrating assistance agents into the operations of non-visual GISs can afford many methods to overcome certain functional barriers non-sighted users may face. Assistance agents can take many forms. They may be basic scripts that automate and speed up the completion of difficult computations and spatial analysis tasks. Examples include sorting or search tools that can filter out, reorganize or find particular map features based on user selected criteria and route planning tools that can calculate the best path between two locations across a mapped landscape.

More sophisticated advanced assistance agents mimic human-human interactions and allow disabled users to remain independent in circumstances where external human assistance would otherwise be necessary. Advanced assistants have been deployed with success in mobility aids produced for non-sighted people and can help maintain a user's independence by providing an alternate source of guidance than a human aid (Bourbakis 2001). Examples of intelligent assistance agents include help services that provide instructions and guidance when a user is unsure how to proceed or carry out their desired tasks. Alternatively they could actively transcribe verbal input from a user or offer automatic corrections (i.e. spell check, auto-complete, snap to grid, etc).

4.3.3.2 Provide intuitive interactions

The process of learning to use a novel computer system can be daunting for any user, whether sighted or not. A system that affords intuitive operations, which are those that match what the user naturally expects, will provide the most expedient and least difficult learning curve. Burger (1994) notes that non-sighted people invest much time and effort into acquiring and refining methods and working habits for information access in daily life. It is, therefore, important that these practices and the investments of energy they were derived from are respected. A system that provides intuitive interactions does just that. Burger also recommends that new conventions or practices that differ greatly from a user's expectations should be introduced slowly and clearly through a process of defined and gradual transition if possible. This reduces the disorientation and frustration that may accompany the adaptation period required to become familiar with foreign interactions.

The physical form of any human computer interface will suggest and prompt particular movements and actions (Benford et al. 2003, Challis 2000). Rauterberg (1999) explains that the most intuitive and natural user interfaces and human-computer interactions are those that mimic real world activities, such as the human-environment, human-object, and human-human interactions. Natural human-environment and human-object interactions are guided and constrained by real world laws of physics. Human-human interactions are based largely on verbal interactions like speech and language exchange and non-verbal interactions like body movements and gestures. Creating congruence between real-world and VR interactions builds upon the habits and experiences users gain throughout their other lived experiences. Systems that facilitate this congruence are said to embody a new generation of human-computer interfaces and often employ novel technologies for recognizing real-world interactions. These may include speech recognition systems that recognize verbal interactions, computer vision systems for body movement and gesture tracking, and haptic modalities for physical interactions. Finally, it is important to recall that what may presumably be intuitive for an interface designer may not necessarily be the same for a given user. Assumptions about the emergent properties of an interface should be avoided in favour of thorough user assessment.

4.3.3.3 Facilitate smooth and refined operation

Smooth and refined computer interface operations are one of the attributes most notably appreciated by participants in various evaluation tests of non-visual GISs (Iglesias et al. 2004). Developing elegant input and output interactions that manage complexity well are critical in facilitating smooth and refined operations. Harrower and Sheesley (2005) suggest that map content and controls should be live-linked or tightly coupled so that requested changes to the map display occur immediately when a users manipulates a control or enters a command. This ensures that users are not made to wait for the tasks they initiate to complete. The more immediately responsive an interface is when processing commands from the user, the smoother and more refined its operation will feel. If there are long delays and pauses while processing occurs completing tasks can feel very cumbersome and tedious. Ensuring that adequate processing power and memory is available in the computer running a non-visual GIS is critical for providing smooth operation.

Ensuring smooth and refined operation also requires attention to other design aspects as well. Sjostrom (2002) notes that in tactile and haptic representations smooth bends and curves are preferable to sharp angles and abrupt corners because they are easier for users to follow. When a user is tracing the path of a line and reaches an abrupt perpendicular intersection the tendency will be to lose contact and continue tracing in the direction of the original line. However, if the line curves or bends gradually to make a perpendicular intersection, then following the proscribed path becomes much easier.

4.3.3.4 Provide constant feedback and maintain synchresis

The quality and quantity of feedback that a GIS provides in response to a user’s actions is a key aspect of usability. Clear and concise feedback supports rapid perception and understanding when information must be mentally inferred from sensory feedback provided in response to user input activities. As such, when developing computer based approaches for map access, if richer and more meaningful sensory feedback can be obtained from a system then better mental inferences about the content of an unseen map can be made.

Burger (1994) notes that well designed systems place the burden of communication on the computer, rather than on the user. A mapping system designed for effective feedback should, therefore, proactively offer information rather than disclosing it only when requested. Burger also identifies several instances where feedback should be provided to the user. Primarily, the user should be made aware of the state of the system, which includes what it is doing or waiting for and what interactions are available at any point in time. Feedback can be provided to inform a user that a command has be accepted and is in progress or when a task has been completed. Feedback may be used to prompt a necessary action or delay further actions until the appropriate time (i.e. until a new map scene is loaded, zoomed, moved, etc). Guidance feedback is needed to maintain positional accuracy or follow a predetermined path when manually moving through and exploring a map scene (Sjostrom 2002). For instance, a sound clip could be played to let users know when they have left a predetermined path or, alternatively, when they are moving closer to or further from a targeted point of interest. Detailed feedback is also particularly necessary to convey error messages or explain how and why an intended action has failed. Establishing an effective and consistent feedback regime can also help indicate when a system has crashed or become unresponsive if the expected feedback is not provided in the event of a system error.

Every event that occurs when using a GIS should be denoted by some sort of confirmation feedback (McGee, Cohen and Oviatt 1998). This feedback must be clear; it must not interfere with map content representations and it must not have any latency or lags that could confuse the user. Braun (2006) refers to the concept of **synchresis** to describe the need for synchronization, congruence or immediacy between action and effect, particularly in the relationship between what one does and what one hears. The real-world delay between an action and its sound response is thought to be approximately ten milliseconds (Hermann and Ritter 2004). Any latency between an action and its feedback response greater than this in a non-visual computer system will only serve to confuse the user. Systems should be sensitive enough to immediately detect subtle movements or actions made by the user, such as body movements, voice commands, or gestures. Dumas (2009) asserts that time constraint is highly important in multi-modal systems and it is imperative that all modalities should be synchronized. To do this he suggests that a synchronization mechanism or management system should be employed to curtail potential causes of feedback latency.

4.3.3.5 Provide memory aids

Map exploration can place an immense demand on a user’s memory capacity, particularly when only serial exploration strategies are possible. Serial map exploration can be very laborious and time consuming to an extent that disorientation and memory errors often occur. It can be very difficult to internalize the complete inventory of features plotted within a map field without some form of external memory assistance. Memory aids provide mechanisms for marking and subsequently returning to a previously encountered point of interest (Wall and Brewster 2004). Memory aids can be classified into two categories: direct and indirect. Direct memory aids explicitly mark or flag a specific map feature so that it can be easily revisited after further exploration. These aids can isolate critical features within spatial representations, such as the origin of an exploration pattern or the most applicable feature found during an ongoing guided search (e.g. the tallest bar on a graph). Indirect memory aids are global reference features like bookmark lists or history tables that allow past activities or content to be tracked and recalled on demand. Other forms of indirect memory aids that are meant to denote which parts of a map have been explored have also been studied (Paciello 1997). For instance, hypermedia links that have been visited in the past can be given an indicative characteristic. Alternatively, a user exploring a tactile map could remove tiles placed over top of content to reveal new information and track which regions of the map have been explored.

In their research on memory aids, Kildal and Brewster (2007) provide a list of characteristics that memory aids should possess. They should be easily added and removed and not limited in number. Each aid should be easy to find and should remain fixed and/or stationary unless explicitly moved by the user. Employing a memory aid within a map should not alter or obscure the map’s content at the location where it is placed. Finally, memory aids that mark a feature or point of interest should integrate other search and query tools, such as tagging or categorization, to facilitate more advanced analysis and information seeking.

4.3.3.6 Create constraints where necessary

Sjostrom (2002) recommends that constraints should be integrated into the design of multi-modal human computer interfaces in order to prevent users from performing actions that would inadvertently impair their mapping experience, damage or destabilize the GIS system or cause unexpected changes to the system’s operations. Employing constraints can impart structure to a system, prevent information loss, avoid confusion, and provide a degree of error tolerance by preventing undesirable circumstances from occurring. Constraints can be hard and active, wherein a system will not allow or actively opposes certain actions, or soft and passive, wherein a system confirms that a particular action is actually intended before it is allowed. Similarly, constraints can be mechanical and/or physical measures or virtual rules that restrict how a system operates. Affixing interface hardware to a desktop surface so that it cannot be moved is an example of a hard physical constraint. Providing a confirmation sequence to confirm that a user wishes to exit a program without saving changes they have made to their work is an example of a soft, virtual constraint.

Integrating a degree of configurability to software constraints can also provide a greater degree of control over the user experience (Patten and Ishii 2007). Constraints should also not be so imposing that they prevent free and innovative use of a non-visual GIS. They should ensure that a system always operates as expected no matter what the user does.

4.3.4 Emphasize context sensitivity and adapt to users’ changing needs

4.3.4.1 Emphasize easily updatable and distributable spatial information

Much of the value of GISs can be attributed to their role as information gateways. These systems allow users to navigate, access, create and share information among many interconnected and widely located sources. The ability to distribute self made maps provides the opportunity for discussion, feedback and contribution to communal and collaborative cartographic enterprises. However, many factors must be attended to in order to achieve the means for updating and distributing spatial information, the most essential of which are a form of dynamic display and a mechanism for dissemination.

Digitized information can be distributed in many different ways presently. The transfer capacity of modern broadband internet connections and storage capacity of physical media devices make sharing data quite simple if the appropriate hardware and software are provided. Modems, optical drives, card readers, or wireless network interfaces are examples of devices that can be used to transfer spatial data from one GIS to another. Distributable information may also functionally exist in many locations at once, meaning that there is not necessarily a single hard copy of a published map. Given that, non-visual GIS devices should have some form of local storage such as a hard drive where data files that are acquired from a remote source can be stored. Systems designed to catalogue and organize different map data files have become integral components of visual GIS products and will eventually become necessary as non-visual GIS use and the volume of data files that non-sighted users wish to access expands.

Non-visual GIS clients must have some form of output functionality, such as the ability to print, save, send, or export map data files, as well as input functionality, such as the ability to open, scan, browse, or import map data files. If these functions are not available, the utility of a non-visual GIS will remain limited. Map files must also have a form of shared data language that will allow identical images or base map scenes to be produced from any computer. If GIS devices do not speak the same language then data cannot be successfully distributed even if there are no physical transmission barriers. Ideally the data files used by non-visual GISs will be the same as those used by traditional GIS formats (See Mankari et al. 2010).

4.3.4.2 Support a wide spectrum of uses

Versatility is seen as a core goal of human centered systems and GISs can be, if designed correctly, tremendously versatile tools. The greatest value GISs offer, beyond simply affording the passive consumption of spatial data, is the ability to produce new spatial information and actively participate in geographic discourse. In order for non-visual GISs to be considered serviceably equivalent to the offerings available to sighted people, all potential uses of a GIS must be accommodated.

GISs facilitate many different mapping activities, beyond the production of maps. Frietag (1993) highlights four major types of map use: reading, analysis, interpretation, and orientation/navigation. Viable non-visual GISs should support tasks in each of these areas.

It may be entirely impossible to predict the complete range of uses that a non-sighted individual may have for a non-visual GIS, thus an open ended design approach is desirable. Actual map use instances and contexts may be much different than the intended circumstances a GIS designer foresees. By not prescribing a single intended use for a non-visual GIS, a greater number of actual map uses may be possible.

4.3.4.3 Create growable systems

Though certain criteria may characterize the vast majority of anticipated users for a non-visual mapping system, there can be no universal criteria that define all users equally. Users may range between novice and expert, young and old, petite and large, slightly to severely visually impaired etc. Marcus and Van Dam (1991) note that "designers should make user interfaces natural for the novice user but also devise special conventions for the expert 'power' user that require greater learning time and cognitive load" (p. 52). Furthermore, no user will remain static during the duration of their use of a mapping system. With practice, novice users will become more proficient. Young users will both age and grow to become larger and stronger as well as more educated with time. The vision of slightly impaired individuals may deteriorate. With success, non-sighted users who become more involved in geographic activities will need a greater diversity of map products and access to more sophisticated geographic information. Given these factors, it is important to create systems that are flexible and can grow and adapt to user's changing needs and priorities.

Erin (2009) notes that children and adolescents are most receptive to novel technologies and that creating devices that can be used by children is an important step towards creating technologically savvy adults. To this end, a single non-visual map interface design should be able to support the needs of children (for learning, gaming and education) and then transition into supporting the professional or domestic needs of adults. Avoiding technology that is vulnerable to obsolescence is also important for non-sighted people, who have limited resources to invest. Successful non-visual mapping systems should be designed with a capacity for upgrading and enhancement in mind.

4.3.4.4 Emphasize portability

Advancements in computing technologies have made portable personal electronics a major component of contemporary life and have also accelerated university accessibility research (Vanderheiden 2000). For sighted people, portable electronics provide many different opportunities for map access, particularly with respect to orientation and navigation tasks. Location aware GPS and web enhanced devices, such as smartphones, personal computers (notebooks, netbooks, tablets, PCs, etc.), digital cameras, and vehicles, now provide the ability to access maps, geo-reference digital files, search for nearby amenities, ascertain exact personal coordinates and log travel paths over time for later review. Each of these spatial functions is an important avenue for mapping yet most are unavailable to non-sighted people for whom personal mobility aids are quite basic and limited to the tasks of route planning and journeying.

Portable non-visual mapping devices should meet a number of criteria. They should be lightweight and compact, easily stowable, and wireless. When used in public, the appearance or operation of a portable device should not attract unwanted attention to the user (Shinohara 2006). From a functional standpoint there are many beneficial affordances that personal mapping devices can offer non-sighted people. Portable location aware devices can assist non-sighted users to track their movement through space. **Geotagging** features can be used to locate and spatially reference digital files, such as audio recordings that may be made at a given location. This could enable a form of meaningful annotation by allowing users to record discrete or ambient sounds from a particular location and pin them to a map to provide a reminder of the character of a point of interest when exploring the map.

4.3.5 Create open and inspectable computer systems

4.3.5.1 Integrate tangible & analog components

Studies have shown that integrating tangible components and everyday artefacts into non-visual information systems can be very beneficial (Pielot et al. 2007, Riedenklau et al. 2010a, Ishii and Ullmer 1997). Tangible components have very concrete forms that are not mediated by a display device. They are multi-dimensional and most can be easily grasped and held in hand. Many artefacts have a distinct character or physical presence that can be recognized more easily than virtual approximations. Certain artefacts may also be familiar to users from other contexts, which eases the identification process when using a novel mapping system.

Many instances can be provided wherein tangible components and everyday artefacts are integrated into non-visual mapping systems with reasonable success. In Pielot et al.'s studies (2007), a toy rubber duck is used as a manipulable avatar representing the user's presence in a map scene (Figure 3.5). The duck was selected as an effector for this scene because it has a very distinct shape and physical character, was familiar to the study's participants, and could be easily handled. Riedenklau et al. (2010a) also use tangible components in their non-visual interface in the form of motorized blocks that can move independently within a map scene to approximate distributions of scattered data points. Users are able to inspect the system by picking up these blocks and allowing them to return to their place. Integrating these objects creates a richer system that can be inspected through physical manipulation and inspection.

4.3.5.2 Respect established standards

A variety of established non-visual publishing and accessibility standards have been created by various organizations to improve products intended for non-sighted and/or disabled audiences (Shinohara and Tenenberg 2009, Moreno et al. 2011). These standards and guidelines have been created by various regulatory bodies, service agencies and research groups with the intention of elevating and unifying the quality and character of digital information products. Standards may concern many different areas of non-visual cartographic practice and GIS design, including: information organization strategies, multi-modal symbology, data file types, technical specifications and so on. Many governing bodies also have region specific independent publishing standards, such as government publications, content published for public sites and services like national parks, or regional school boards. These location specific standards should also be respected by the design of non-visual maps. Adhering to these standards will support audience acceptance and user familiarity with new map products. Consistency among information sources is a major benefit for non-sighted people as it reduces the time spent learning new publishing conventions and makes publication formats more predictable.

Many technical standards, such as the OpenGIS consortium's interoperability standards define common data exchange terms that allow GIS packages to work together and share common datasets (Cartwright et al. 2001). Following standards such as these will avoid the creation of disconnected island of non-visual cartographic products that cannot work or share data with visual GIS products already in use. Adopting industry standard technical specifications, such as wireless protocols (Bluetooth radio and wireless USB), coding languages (Java, XML, C++, etc) and spatial data types (.shp, .CAD, .SVG, etc) encourages integration with existing user groups. Eschewing proprietary specifications allows a greater range of pre-existing consumer products like peripherals and datasets to be easily integrated into new non-visual GIS systems.

Standards need not always be seen as absolute rules that predefine the output of a project. In most cases they simply set a minimum level of salient criteria that allow a product to remain relevant and function appropriately in a user's domain (Borodin et al. 2010). These criteria can often be met or exceeded in a variety of different ways. Some authoring organizations also provide validation services to ensure that their guidelines are correctly implemented. However, it is important to note that even when content is created in full compliance with established standards, it is not automatically easy or even possible to use without further refinement.

4.3.5.3 Label everything well

An inability to identify map features and GIS interface components is a significant functional barrier for non-sighted GIS users. Paciello (1997) notes that retrieving alternate non-visual descriptions or labels of map objects is often a significant challenge. Some studies (Heller 2002) suggest that the misidentification of objects in tactile representations is as often due to labelling failures as it is to perceptual mistakes made by the user. As such, employing effective and comprehensive labelling strategies is critical to overcome this functional barrier against map use. Inadequate labelling will also decrease exploration efficiency as additional time may be spent looking for and identifying sought after items on a map. Demands on users' working memory may also be increased if the identity of map features that are not immediately evident must be consciously remembered.

Effective labelling accomplishes many things. It contributes to the distinguishability of similar items (Shinohara 2006) and it allows users to create a mental inventory of spatial content they have discovered. This can be very useful when trying to find salient points of reference. Effective labelling also helps users maintain a clear distinction between interface components and represented content (Sjostrom 2002). For instance, a fold or wrinkle in a tactile map may inadvertently be mistaken for a raised line if the user cannot rely on labels to identify proper map features. The creation of a consistent labelling scheme that allows users to predict where and how labels can be found in relation to map features is also beneficial. Miele, Laundau and Gilden (2006) note that collocating labels with conspicuous points of reference, such as where features intersect with the edges of a map, is one way to reduce map clutter and label ambiguity. While this approach is not without difficulty, as in instances where map features do not intersect with map edges, it does illustrate that labelling schemes can be devised to organize the intergradations of labels into map scenes and often reduce clutter or increase label predictability.

Many different options may be considered to provide effective labels in a non-visual map product. Ideally, labels should be designed to be immediately evident or to self announce themselves upon discovery by the user. Audio playback is often an effective means for achieving this sort of labelling. When a map feature is activated, whether by a finger on a touch sensitive tactile map or by a virtual probe in a haptic soundscape, an audio cue can be played to denote the identity of the item. Referential sound symbols may also be used in lieu of labels. For instance, the sound of waves can represent bodies of water. Alternatively, feature captions can be used to provide text that can be read by a digital screen reader (Paciello 1997, Rassmus-Grohn 2006). Audio labelling has become preferable to Braille in recent years due to decreasing Braille literacy rates in the non-sighted population, difficulty rendering Braille text in haptic and virtual really interfaces, and the relatively large area occupied by Braille lettering.

4.3.5.4 Provide complete and accessible documentation

Obtaining technical information that describes and explains how a new human computer interface or non-visual GIS is constructed or designed to operate may be vital for non-sighted people. For this reason, detailed and complete technical documentation should be accessibly developed for all non-visual mapping systems. The ability to independently explore the operating mechanisms of a non-visual GIS to become familiar with its operation is an important foundation for autonomous participation in geographic discourse. Providing complete documentation also gives non-sighted users with programming expertise more agency to participate in cartographic proceedings by applying their skills to the continued development and refinement of non-visual GIS solutions.

Three particular areas where complete documentation is important are command parameters, programming source code, and metadata for spatial information. Documenting how different commands can be employed by the user will expedite the learning process by removing trial and error learning guesswork and will create more competent users who are familiar with the full capacities and functionality of the system they are using. Programming source code documentation allows users familiar with computer science concepts to better understand the structure and design of the software they are using and alter it as they see fit. Finally, metadata documentation for spatial data provides concrete reference information that defines the authorship, context, purpose and background of data files that can be accessed by a non-visual GIS. Metadata is often thought of as critical component of spatial data packages (Antonelli 1999), but it is seldom addressed in literature concerning non-visual cartography.

Many precedents for complete and accessible GIS documentation exist in the visual side of the field. Open source projects freely publish the source code of their products and often include meticulous descriptions to explain the purpose and mechanics of significant sections of code. Alternatively, ESRI, a major publisher of industry standard GIS software maintains an entire website dedicated to providing extensive documentation and help support for their ArcGIS products (ESRI 2011b). Resources available through this site include software update logs, a terminology dictionary, troubleshooting guides, programming explanations and code examples, known issue databases, and installation support. This documentation is essential for sighted users of ESRI software products. Any non-visual GIS product should, therefore, have a reasonably equivalent documentation catalogue to support non-sighted users.

4.3.5.5 Emphasize design consistency throughout the system

To increase the effectiveness of a non-visual GIS, the design style and cartographic conventions initially introduced, plottings and interface format, must remain consistent from usage to usage.

The choices made regarding a map's form and format will establish the user's expectations at their first introduction to the system. All subsequent impressions of a mapping system must, therefore, conform to this initial expectation or risk confusing the user (Sjostrom 2002). Ensuring design consistency respects the users established expectations regarding interface component locations, employed metaphors, terminology, and reference schemas and avoids confusion (Reeves et al. 2004a).

Users will expect what they have already experienced previously and may be disoriented if elements have moved, changed or disappeared. Furthermore, if a map user is attempting to describe some aspect of a map or system to another person, significant confusion can occur if both people are not exploring identical interfaces.

Even if they are not necessary in a given context, the presence of particular interface elements can support a user's orientation process (i.e. the zoom control is always to the left of the pan control). Although particular interface elements may not be needed in all contexts, they should not necessarily be removed if its absence would harm the users' orientation and exploration strategy. A button for a certain task may not be needed in some contexts (i.e. when a field is panned to the western edge of a map scene the pan left button is no longer necessary). However, that button should not be removed if it is expected to occupy a particular location. Instead it should be conspicuously disabled so that the user is aware that it is no longer possible to move further west in the maps scene but can still use the button as a point of reference.

4.3.5.6 Always provide contextual information

Petrie et al. (1997) note that providing map overview descriptions and opportunities to gain cursory information about map scenes can significantly enhance information uptake and comprehension. They can also enable users to focus their exploration procedures for novel map content and reassure users of their exploratory inferences. Contextual overviews of map scenes provide users with summaries of data, key points of interest, and relevant background information that allows generalized initial interpretations of map scenes to be established and subsequent exploration procedures to be refined.

Contextual overviews can take many forms. For instance, they may be basic inventory lists of mapped features and contents (i.e. 'this scene contains the following items: ten buildings, one river, three statues, and one park'); verbose descriptions (e.g. 'The displayed map depicts the region surrounding the City of Calgary from the Rocky Mountains at the western border to the Alberta-Saskatchewan provincial boundary that runs north to south along the 4th meridian...'); or simplified generalizations distilled from more complex data patterns and trends (i.e. simplified polygons used to represent a region where clusters of individuals features exist). Ideally contextual overviews should be dynamically and automatically generated by intelligent software algorithms. However, the complexity of this task may require human authorship for most overviews of non-visual cartographic content.

4.3.5.7 Provide well defined points of reference

Effective points of reference are critical for navigation and orientation in real life as well as when using mapping systems (Sjostrom 2002). Both the content and interface of a non-visual map should be augmented with conspicuous and easily recognizable points of reference. Effective points of reference facilitate localized orientation and allow the map users to navigate within mapped content and around a computer interface (Burger 1994). Harrower and Sheesley (2005) observe that the need for local and global orientation cues increases proportionally with the size and complexity of information representations. Points of reference help users determine spatial relationships between discovered items and provide cognitive anchors for mental maps. The content of a map can be used to provide points of reference using any of the elements identified by Lynch (1960) and other spatial theorists (nodes, paths, edges, districts or landmarks). For instance, in a haptic soundscape map of an urban region, the main street of a neighbourhood could be given a distinct sound cue that signifies is prominence as an important path. Alternatively, an iconic building or central plaza could be augmented with a unique sound cue to provide enhanced prominence as landmarks within the scene. Many map features naturally lend themselves to the role of reference markers if that is also their purpose in reality. Marine buoys, such as those emphasized in Simmonet's (2007) mapping system for non-sighted sailors, exemplify this type of content. Other ways of integrating points of reference into a map scene include overlaying graticules or isopleth lines, which can audibly self announce themselves with spoken labels or sound clips when passed over (Rice et al. 2005a).

Points of reference can be integrated into interface in many ways as well. The boundaries of a map can be physically enframed to create hard barriers that signify a map's furthest extents. For instance, a picture frame or hard edge can be installed to emphasize the edges of a tactile map, or a virtual box can be created around a map model rendered in a haptic soundscape. Map interfaces that facilitate kinesthetic exploration can be constructed in ways that integrate their physical presence in a room. A relief map can use the surface of the desk as a point of reference to signify sea level or any other base reference elevation.

4.3.6 Create engaging and enjoyable non-visual geographic information systems

4.3.6.1 Provide Pleasant Sensations

Maps have long been recognized as having strong aesthetic qualities. Ensuring that a non-visual GIS provides pleasing and agreeable sensory stimulations should increase user satisfaction. The sensory feedback that a non-visual mapping interface provides its user must not cause any discomfort or unpleasant physical sensations. Vanerp (2002) notes that devices used as dynamic tactile information displays, such as electrodes and vibrators, can inadvertently cause discomfort if activated for too long or at overly intense output levels. Exposure to painful sensory experiences is generally thought to have no demonstratable usefulness for mapping and graphic interpretation (Golledge, Rice and Jacobson 2005). Respect for human stimuli comfort ranges is also important for this reason. For instance, shrill or uncomfortably loud audio playback will not be appreciated by most users.

While aesthetic tastes often vary dramatically from person to person, some representational approaches are more universally disliked. Herman & Ritter (2004) note that some musical or tonal relationships can temper the experience of an auditory data display. Certain combinations of notes and harmonies are pleasing or emotive, while others are dissonant and irritating. Tailoring the audio feedback a multimodal computer interface creates in order to avoid undesirable audio output is one way to create more pleasureable map use experiences. Similar care should be taken for all other sensory modalities employed by a non-visual GIS.

Various studies have also found that certain materials are known to be less preferable when used to create tactile maps or interface contact points (Jehoel et al. 2005, Yoshioka et al. 2007, Pappas et al. 2009). Johoel, Ungar et al. (2005) conducted empirical studies to determine general user preferences towards particular map substrates. The author found that the majority of their participants firmly preferred rough substrate surfaces over smooth substrate surfaces, despite variability in the task efficiency of either material.

Lauriault and Lindgaard (2006) note that map users’ varied opinions concerning what makes for a pleasant or disgusting scent or taste is one reason these stimuli types are rarely used as cartographic modalities. However, some attempts using generally well liked tastes, such as modeling map shapes out of chocolate to create edible regional maps, have reportedly been quite appreciated by test participants.

4.3.6.2 Maintain compliant representations and semantic fidelity

One of the most important considerations for creating geographical products with non-sighted users in mind is ensuring that meaningful content is provided and semantic fidelity is maintained. Respecting this guideline involves avoiding arbitrary representative characteristics for map extracts by choosing to emphasize only object properties that are salient and meaningful to the non-visual user. What may be meaningful to a sighted map designer may not necessarily be meaningful or appropriate for a non-sighted map user. For instance, the silhouette of a cresting wave is often used as a pattern to represent water on tactile maps, even though knowledge about the shape and form of a wave is typically acquired through visual perception.

Figure 4.3 Extract from the Braille enhanced Tactile Atlas of Canada (NRC 2002b). Some symbols, indicated by arrows have been cropped around the water's edge.

Maintaining semantic fidelity involves creating content that accurately recreates its intended subject. For example, sound clips of bird song or waves should be immediately recognizable as birds singing or waves crashing, as opposed to random chirps or white noise. Furthermore, only complete symbols should be used to ensure map legibility. Representative symbols should not be truncated or cropped to fit into an available space (Figure 4.3).

Choices regarding representative characteristics to be used for non-visual maps should be vetted by non-sighted users rather than based upon the assumptions of sighted technicians (Shinohara and Tenenberg 2009).

4.3.6.3 Support inconspicuous operation

Social considerations play an important role in personal perspectives on technology use. As such, the way a technology user believes they are perceived when using an assistive object or device significantly influences how they feel about that item's overall utility. Various researchers report that some non-sighted users will eschew products that they feel are overly conspicuous or that they feel may advertise a disability (Calder 2010b) as they do not wish to draw undue attention to themselves in social settings (Shinohara and Tenenberg 2009). For this reason human computer interfaces designed to provide multi-modal access to spatial information should also support inconspicuous operation modes and features. Supporting inconspicuous operation can also benefit non-sighted users by ensuring that they can still attend to important background cues, such as another person entering a room or a telephone or doorbell ringing, when using an assistive device (Calder 2010a).

Many approaches can minimize the likelihood that users may feel self-conscious when using assistive devices. For instance, sounds and synthesized speech can be isolated for the user without drawing the attention of others by playing audio content through headphones rather than loudspeakers. Likewise, choosing quiet operating mechanisms and dampening sound or vibrations produced by haptic or force-feedback devices can allow users to easily share tables and work spaces without both parties experiencing the forces the device creates. Scent outputs have also been explored as a medium for encoding geographic information (Lauriault and Lindgaard 2006), but the airborne dissemination of scents makes this modality particularly conspicuous so producing scents passively (e.g. scents release when areas of paper are scratched), rather than actively (e.g. fragrances are sprayed into the air) is preferable. Some computer vision and motion capture systems require markers that, although they are technically necessary, are still highly conspicuous (Figure 4.4 and Figure 4.5). Choosing unobtrusive computer vision technologies that rely on background extraction techniques or that use light markers outside the visible spectrum are preferable in these instances.

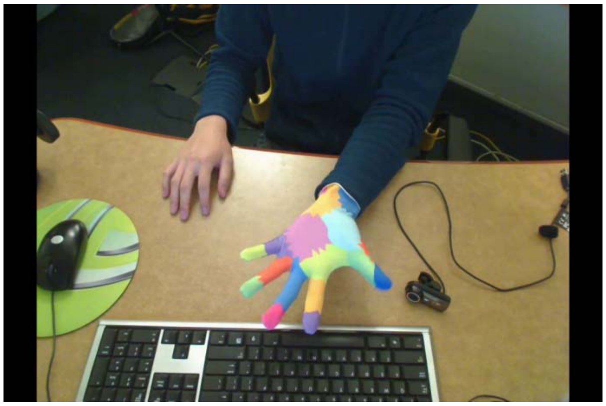

Figure 4.4 MIT Hand Motion Capture Glove (Wang and Popovic 2012).

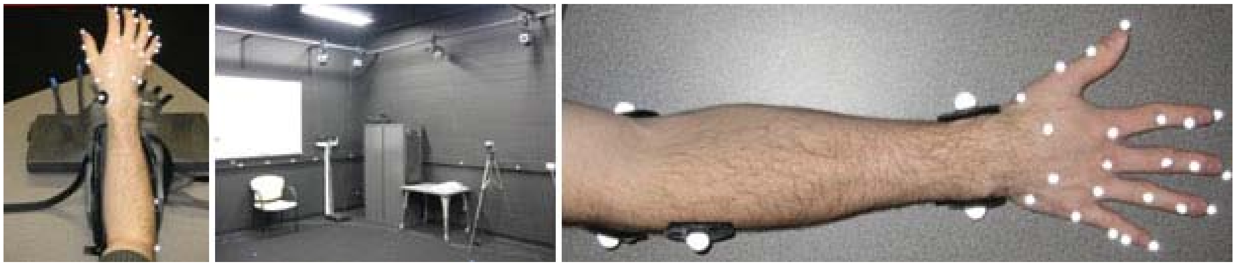

Figure 4.5 Visible Light Markers used for Hand Tracking (Rahmatalla 2012).

4.3.6.4 Make systems easy to setup, activate and maintain

A central premise of the universal design paradigm is that items designed with universal access in mind should require low effort. This refers primarily to ease of use factors, but also to time and energy investments as well. In order to respect this premise, non-visual mapping systems should require little effort to independently install, activate, and maintain. Inadequate robustness is a serious vulnerability for any system. A design that does its intended job well but cannot be used without significant investments of time and energy is not likely to gain user acceptance or traction in its intended market.

Technology designers of non-visual GISs must ensure that the human computer interfaces employed for non-visual mapping systems need minimal assembly, calibration or cleaning. If they are absolutely necessary, steps should be taken to automate these tasks. After acquiring a non-visual mapping system or transporting it to a new location, the user should only have to remove a minimal amount of protective packaging, place the device in a suitable location and connect a power source to complete the setup process on their own. This sort of approach can speed up access to spatial information and prevent the confusion and frustration that may occur if many cables and wires had to be connected between devices (as is the case with many desktop computers).

4.3.6.5 Ensure enjoyable and fun operation

In addition to aesthetic considerations, affective responses are also important determinants of a GIS system's merit and viability. Users' impressions of a non-visual GIS are highly dependent on the quality of their experience. Systems that provide a fun and enjoyable experience are more likely to gain acceptance and preference than those that offer the same degree of functionality without any regard to pleasurable use. Users whose experiences with a novel non-visual GIS are enjoyable are more likely to be optimistic about the system's viability than those who did not enjoy their experience using a new system (Schneider and Strothotte 2000). Systems users characterize as "fun to use" are also typically recognized as quite successful in other respects (Kane, Bigham and Wobbrock 2008).

Several factors can contribute to an enjoyable experience using non-visual GISs. Most significantly, the system can be designed to offer geographic information in the context of games and interactive puzzles. Approaches that use games to convey spatial information are reported to be very successful if correctly integrated into a cohesive geographical curriculum. Watanabe (2006) and Sanchez (2006) note that basic games based on spatial premises, such as whack-a-mole, tic-tac-toe and battleship are often adapted for use as non-visual tools for geographical education in school settings. The amusement that non-sighted students experience from alternative information modalities, such as games and puzzles, often helps to prolong their attention spans, decrease fatigue and foster collaborative learning practices. Indeed, many audio based games have been created that have strong egocentric spatial game play aspects, such as orientation, exploration and navigation (Sanchez 2006, Creative Heros Creation Studio 2011)

Aspects other than gaming opportunities also contribute to fun and enjoyable user experiences with non-visual mapping products. Obviously the user should not feel embarrassed to use a product, which relates to design considerations for inconspicuous operation (Shinohara and Tenenberg 2009), nor should they feel uncomfortable or unsafe (which relates to design considerations that respect physiological limitations). Furthermore, the length of time that a GIS product is used may also affect user's affinities. Maclean (2008) notes that repeated, brief exposures are most productive when using tactile maps. Developing maps that minimize total and individual session duration should, therefore, support more enjoyable experiences. In essence, the more quickly a task can be accomplished the more satisfying and enjoyable the system will seem.

4.3.6.6 Provide training exercises

It has long been recognized that learning to use a new and unfamiliar computer interface or program can be a very difficult and demanding task (van Aalst, Carey and McKerlie 1995, Carroll and Carrithers 1989). If no training accommodations are provided to help new users become familiar with the technology they intend to use then their chances of success are severely limited. Andrienko et al. (2002b) explored many usability issues related to user training that arose during the development of their CommonGIS platform. CommonGIS is a geovisualization tool intended to provide advanced mapping and data analysis opportunities to as broad a community of users as possible. To create a truly inclusive platform the authors found that the needs of naive users with no prior mapping experiences must be addressed. Based on initial evaluations of their prototype, three significant conclusions were made. First, understanding the meaning and operation of new interactive tools can be difficult, if not impossible, without some form of introduction. Users cannot be expected to guess how a system works. This is particularly true in the case of cartographic conventions as specific training may be needed to clarify the meaning of representative symbols and other design elements such as arrows, coordinate systems, directional symbols, etc. (McCallum et al. 2006). Second, encountering features with unclear purposes makes users feel uncomfortable and apprehensive. Users often prefer that such features be excluded from the system entirely. Finally, naive users typically adhere to static mapping principles since these are what they are most accustomed to. The possibility that an interface could be used to facilitate interactive data analysis may not be immediately evident. Addressing these functional barriers against map use for new users, with a particular concern for the unique needs of non-sighted people, will make non-visual GISs much more viable.

The purpose of training exercises is to help users understand the purpose of a tool and how to use it, to retain acquired skills after a long period of disuse, and to encourage an affinity for new tools rather than apprehension (Andrienko et al. 2002b). Training may be more intensive when introducing a new system or it may be continued and designed to help users progress from novice to intermediate to expert stages. Tutorial features and accommodations for training can be integrated into computerized GISs in many ways. Denise et al. (2008) list a variety of different options to stimulate the learning effects that are needed to improve user interactions. Built-in demonstrations, step-by-step instructions, practice exercises and example scenarios are some of the different methods that can be used to introduce new skills and concepts to new users. Haptic devices have been significantly tested for teaching kinesthetic tasks and gestures used for non-visual mapping. For instance, studies on path guidance (Feygin et al. 2002) and trajectory playback (Crossan and Brewster 2008) have demonstrated that haptic training assistance can improve a user's performance when learning specific gestures or exploration strategies needed to explore virtual shape representations. Ideally, these components should be provided independently so that a separate person is not necessary to help the user develop competence.

4.3.7 Facilitate the provision of core cartographic elements and conventions

In addition to addressing the affordances and design guidelines related to human factors that are listed in sections 4.3.1 through 4.3.6, a successful non-visual spatial data platform must also provide support for certain essential cartographic elements and key information structures. These components provide context and meaning for data sets and allow the user to make better informed interpretations of the content they perceive. Items like titles, borders, graticules, neat lines, scale bars, north arrows and orientation references, legends, captions, metadata, publishing and source references can all be considered basic components of maps that should be included or given equivalent treatment with any spatial data content (Figure 4.6).

Figure 4.6 A sample map illustrating basic map elements such as titles, labels, borders, graticules, neat lines, scale bars, north arrows and orientation references, legends, captions, metadata, and publishing references (ESRI 2008).

4.4 Conclusion

The guidelines provided here cannot be seen as a complete and comprehensive list. Further research will undoubtedly cultivate more insight in time. However, these guidelines should stand as a minimum baseline of criteria that should be met in order to provide appropriate functionality, format and affordances for non-visual GIS. As the breadth of content discussed in this chapter demonstrates, the issues embodied in the problems of non-visual GIS development are truly multi-faceted. They are also highly interrelated. Creating a mapping system that is growable will also support a wide spectrum of uses. Creating constraints against uncomfortable use will support the provision of pleasing sensations and enjoyable experiences. Creating systems that are small and light enough to be portable can also support inconspicuous operation. Looking for synergistic design opportunities wherein one parameter supports another will make for much more effective and resilient information resources than would emerge if each problem were solved individually.

The most important insight to be taken from the requirements engineering process is that issues cannot be studied and solved in isolation. Every parameter and sub-component of a nv-GIS must be seen as an integral part of a broad system architecture. Without a comprehensive approach, vulnerabilities may sneak in to cripple a system before its design is even complete. GIS designers and technology experts must be able to collaborate and share a universal view of issues in this domain, even each individual's field of specialty is relatively narrow. While the priorities that define how and why a system is to be used must be determined first and foremost, the mapping approaches they generate must be tempered by the necessities and guidelines that make a system rich and useful to its users. It is in this manner that the following chapter will outline a novel and accessible prototype for a non-visual GIS.

5 Chapter 5

5.1 Introduction

In his discussion of the evolution of human computer interfaces over the past half century, Van Dam (1997) identified four separate and distinct generations of interface styles. The first generation of basic punch-card and printer based computer systems were superseded by keyboard console mainframes with very simple alpha numeric displays. The third and arguably most well established generation embodies the ubiquitous GUI seen on computers running operating systems like Microsoft Windows, Linux or Mac OS. This interface generation relies heavily on visual symbols like windows, icons, menus and pointers and is operated with a keyboard, video display and mouse [KVM]. Van Dam argues that despite their having defined the status quo in human computer interactions for decades, the first three generations of interface architectures do not sufficiently meet the needs of modern users and computing contexts. The emergence of a subsequent fourth generation of computer interface architectures can, therefore, be seen as an opportunity to transcend the limitations of previous computer designs and build a modern computer for all users.

This emerging cohort of novel human computer interfaces is described as Post-WIMP interfaces. These are computing devices that depart from the visual point and click GUI and KVM interface paradigm. Unlike WIMP interfaces, which do not effectively employ hearing, speech and touch as primary information modalities, the fourth generation of user interfaces is intended to engage all of the senses in parallel, use natural language communication, and support multiple user collaboration. Jacob (2008) elaborates on Van Dam’s conceptualization of Post-WIMP user interfaces by suggesting that these new interface approaches frequently employ **Reality Based Interactions** [RBI], which are those that mimic natural human modes of interaction in the real world. Different forms of RBI may include gestures, speech, body language and posture. These types of user interfaces often mimic real world physics and give user interface elements simulated physical characteristics like mass, texture, field of view and movement.

This chapter describes the design of a prototype fourth generation human computer interface developed with non-sighted users’ unique needs and preferred ways of interacting with the world specifically in mind. This interface will be referred to as the Functionally Separated Multi-

Modal Map Rendering System or Fuse-Map. The overall design of the Fuse-Map interface is similar to various other fourth generation user interfaces like multi-touch computing surfaces or camera based interactive systems. Touch based devices like Microsoft Surface (Banes 2009), the Apple iPad or iPhone and other tablet computers and smart phones are examples of the former, while motion capture oriented devices like the Microsoft Kinnect (Microsoft 2012) and Nintendo Wii (Iwata 2010, Nintendo 2012) gaming platforms are examples of the latter.

The Fuse-Map interface amalgamates and integrates components and design configuration seen in many other commercially available Post-WIMP computer systems. A part of this system that is designed to track the motion and position of a user's hand within the device's work surface is based upon technology used to track a pen across a virtual whiteboard in classrooms and offices. Similarly, speech interaction technology that was originally created to provide video gamers with extended hands free control of their game while operating a handheld controller is used to allow Fuse-Map users to enter commands without removing their hands from the haptic map field being explored. In addition to the pre-existing technologies that have been modified for use in the Fuse-Map interface, certain new and novel interface components are also employed to enhance the systems functionality and create a new mode of computer use that is entirely unique.

5.1.1 Fuse-Map Design Overview

The Fuse-Map interface can be described as a composite device that combines a selection of unique hardware and software components, which include:

- A rendering surface that provides a flat field where maps can be explored;
- A refreshable near-surface haptic display embedded in the rendering surface;
- Computer vision technologies that track user's hands across the surface from above;
- A speech recognition and audio output system;
- A personal computer running the Fuse-Map mapping client and control software.

Figure 5.1 provides a visual illustration of the Fuse-Map Interface. This design is realized in the system depicted in Figure 5.2. Table 5.1 lists each of the individual components shown in both figures. Additional design inventories, photos and illustrations can be found in the provided digital appendices.

While the design of this system may initially appear complex, it is, nevertheless, simply a personal computer augmented with an arrangement of unique peripherals. It is important to note that the user does not have to interact with each peripheral sequentially, as one would with a mouse and keyboard, switching back and forth from one to another. Instead, the peripherals operate synergistically to create a fluid interaction environment on the desktop surface that the user can easily work within.

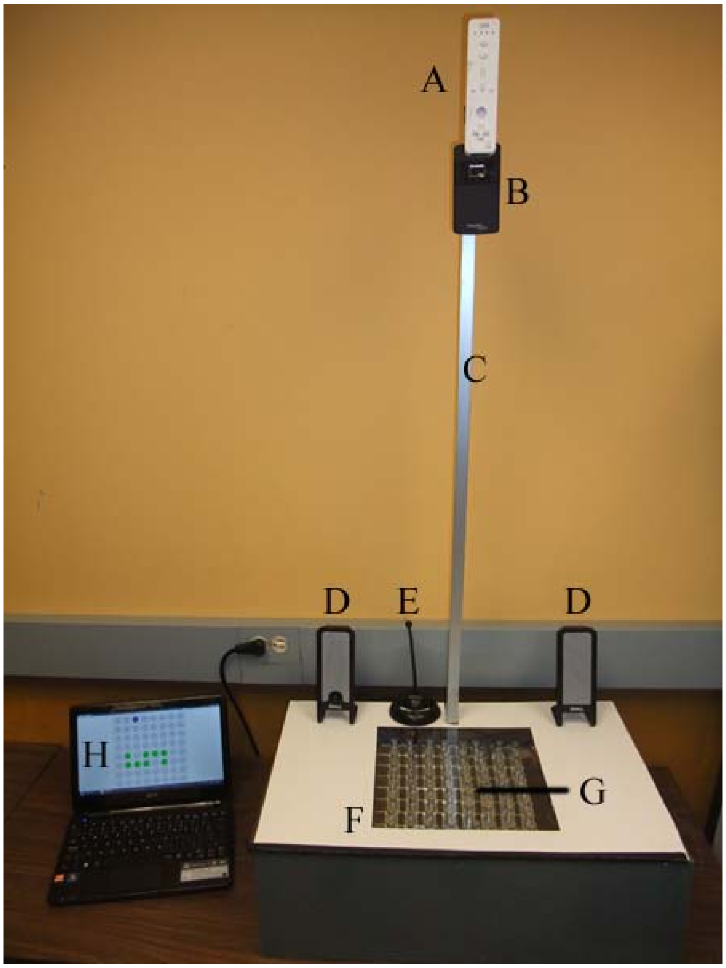

Figure 5.1 The first generation Fuse-Map interface prototype.

Item A	Nintendo Wii Remote used for hand tracking	Item E	Microphone used to capture voice commands
Item B	Digital video projector used to display visual output on the work surface	Item F	Work surface and tactile border
Item C	Mounting armature for devices located above the work surface	Item G	Magnetic Tactile Display embedded beneath the work surface
Item D	Speakers used for audio playback	Item H	Personal computer used to run the Fuse-Map software

To begin operating the Fuse-Map interface a user places both hands upon the desktop work surface [Item F] as if they were intending to explore a traditional tactile map. With a magnetic probe affixed to one or more fingers the user can haptically explore tactile patterns presented by a dot-matrix style 'display' of magnetic **taxels**[12] embedded directly under the desktop surface [Item G]. The magnetic tactile display uses permanent switchable magnets, which are strong rare-earth magnetic that can be switched from an active to an inactive state by a mechanical actuator, in order to create refreshable magnetic patterns. In the active state a magnet is raised up to the underside of the display surface so that its magnetic field extends through the surface material (Figure 5.2). In the inactive state, the magnet is pulled away so that the magnetic field no longer extends above the display surface. When a user passes an augmented finger over an active magnetic taxel a distinct physical sensation will be perceived at that location. Dynamically altering the arrangement of active taxels across the display is the primary method for plotting spatial data in the Fuse-Map interface.

Figure 5.2 Inactive (lowered) and active (raised) permanent switchable magnets used to create magnetic tactile pixels in the Fuse-Map prototype system

The Fuse-Map interface also portrays spatial data through targeted audio feedback. As the user moves their hands within the map scene, an infrared motion camera [Item A] captures the position and movement of a target finger as it moves across the desktop. An Infrared LED affixed to the back of the user's index finger is used to register the location of the user's hand within a defined and calibrated coordinate space (Figure 5.7).

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[12] A discrete 'tactile pixel' created by each point of magnetism activated within the display. Shinohara, M., Y. Shimizu & A. Mochizuki (1998) Three-dimensional Tactile Display for the Blind. *IEEE Transactions on rehabilitation Engineering,* 6.

Interaction protocols developed by Human Computer Interactions expert Chung Lee (2008) allow a Nintendo Wii remote control to track hand motion in lieu of a traditional mouse or track pad. The WiiMote Smoothboard application (Chen and Sun 2009, Boon Jin 2011)**,** which builds upon and refines the protocols demonstrated by Chung Lee, is used by the Fuse-Map interface to translate the movement of a users hand into the movement of an on-screen pointer within an virtual map scene. A soundscape of audio features within the map can thus be explored by moving one's hand within the map field. When a point of interest, typically co-located with a magnetic landmark, is 'touched' then an audio clip or string of synthesized speech output describing the feature is played over speakers or through the user's headphones [Item D].

Although touch sensitive surfaces have been used in other near-surface haptic interfaces (Weiss et al. 2011a) this top down tracking system uniquely allows tactile content and tangible markers or memory aids to be placed below a user's fingers without impeding the sensors that enable the hand tracking functionality.

Various other components are used to complete the Fuse-maps functionality. Voice recognition technology allows the user to issue commands or queries when using the Fuse-Map interfaces without changing hand positions, thereby maintaining spatial coordination and a stable frame of reference. A digital video projector [Item B] and standard video camera aimed downward are mounted above the work surface on the same armature [Item C] that holds the infrared video camera used for hand tracking. The digital video projector allows a visual representation of the map scene being explored to be superimposed upon the magnetic display so that users with residual vision can benefit from an extra channel of information and collaborate easily with sighted users. The digital video camera is used as an experimental tool to unobtrusively observe user interactions and record participant trials for later analysis. The operation of these components is coordinated by a single personal computer [Item H] and together they provide an interaction platform that is highly intuitive, flexible, and semi-synoptic.

5.1.2 Essential Design Premises

The process of critical analysis carried out in the first half of this thesis identified many different requisite affordances that together define the overall criteria for successful non-visual mapping approaches. Six affordances in particular are essential to provide the desired functionality of a non-visual GIS. The specific affordances that were prioritized as core elements of the Fuse-Map's design concept are:

1. An information rendering format that supports transparency, superimposition and the ability to cross reference spatially portrayed data;
2. A multimodal interaction platform that engages sensory channels in parallel without confusion;
3. A dynamic rendering platform that can present many different map scenes from one interface;
4. Interactions that mimic the user's preferred ways of interacting with the real world;
5. Usable memory aids and the ability to annotate or mark-up map scenes;
6. The provision of query agents and computational tools that facilitate high level knowledge synthesis and spatial analysis.

No single component is responsible for the provision of any particular affordance, yet through their integration within a cohesive design all of the desired affordances are achieved. For simplicity's sake, however, the inspiration and approach for each affordance will be described individually in the following section.

Many of the features and interface functionality that will be described in this chapter are supported by the software platform used to create interactive non-visual map scenes. To create interactive multimodal maps for the Fuse-Map interface, a software platform that integrates many different types of rich content is needed. The Adobe Flash (2010) software suite was employed to create the maps used to test and develop this interface. This software package allows authors to rapidly develop highly dynamic scenes where different multi-media attributes and relationships can be attached to unique virtual objects and features.

5.1.2.1 Support for Transparency and Content Super-Imposition

Portraying geographic data in a spatial manner affords the ability to examine and compare what phenomena coincidently occur at a given location. A fundamental necessity for spatial data portrayal is, therefore, the ability to describe and spatially relate multiple attributes or features that occur at the same location. Layering, as it is often described in GIS literature, is seen as the basis of nearly every modern cartographic product. Figure 5.3 depicts the layering concept as it is widely introduced in GIS documentation, textbooks, and lessons.

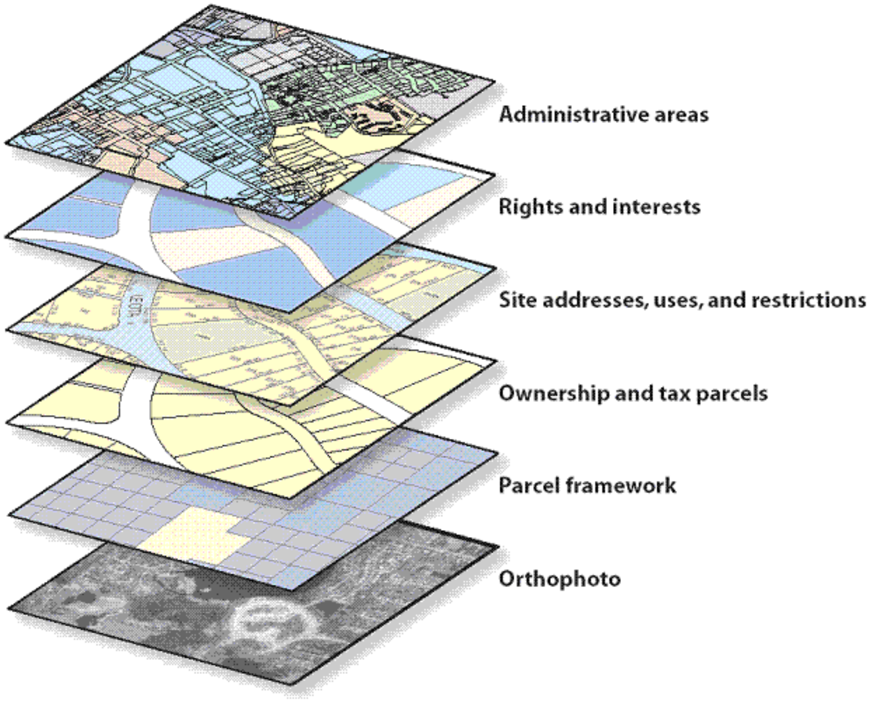


Figure 5.3 Layering information structures in a Geographic Information Systems. (ESRI 2011a)

Examples of coincident geographic phenomena include the elevation of a particular location and the amount of vegetation that grows there; the size and population density of cities situated within a surrounding state; the intersection of one road with another and the travel direction or size of each; and the location of a bus stop along a route and the buses that will stop there through the day. In visual contexts design techniques such as transparency and overlapping geometry are used to convey instances where two things occur at one location. In most non-visual media where touch is used as the primary sensory channel for information uptake there is no functional equivalent for transparency. Once a physical object is placed on top of another the lower layer will be obscured to the touch.

One method for creating a transparency effect that has not yet been extensively explored in non-visual cartography is the use of magnets and magnetic fields. Instead of presenting tactile diagrams using traditional haptic devices, such as force feedback mechanisms, the Fuse-Map interface employs magnetism as channel for rendering arrangements of tactile data. The general inspiration for this interface design can be attributed to the activities of various individuals in the North American community of body modification enthusiasts (Hameed et al. 2010). These enthusiasts have provided reports about their personal experiences implanting rare earth magnets under the skin of a fingertip (BMEZINE 2011, Jarrell 2006, Norton 2006) (Figure 5.4).

Figure 5.4 Rare earth magnets attracted to subdermal magnets within the finger (Norton 2007).

These individuals assert that after a temporary healing and adaptation period, magnetic implants can provide a capacity for the perception and sensation of magnetic fields without interfering with cutaneous tactile sensation. While it was concluded that the subcutaneous implantation of rare earth magnets is not a viable procedure due to safety concerns, the premise that magnetic fields may be used as a novel channel for encoding spatial information for tactile perception remains valuable. This provides a so-called ‘sixth sense’ that can help compensate for vision loss and impairment.

Affixing a ferrous metal patch to the outer surface of a fingertip provides a safe alternative method for achieving magnetic tactile sensation. Exploring spatial data representations created through this sensory channel is procedurally similar to the way that a non-sighted individual would explore the dots and textures that make up Braille text or a tactile map. By activating and deactivating adjacent magnets in a grid matrix it should be possible to encode and represent coarse spatial data that can be observed by users with this accommodation for magnetic sensation. The hardware described in section 5.2.2.1 provides this affordance.

5.1.2.2 Functional Separation and Synergistic Multi-Modal Interaction

An emphasis on human-centered design (Oviatt 2006a, Barthelmess et al. 2006) has emerged as a powerful trend in interface technology development. Human-centered design principles assert that computer systems should be fashioned around the parameters of human ability and physiology rather than forcing users to adapt to the unnatural technology formats. Oviatt, Coulston et al. (2004) posits that more enduring and effective interaction regimes can be created by addressing issues associated with human factors such as cognitive science, linguistics and intuitive user behaviors. Of these issues, the need to manage the cognitive load placed on users by interface output and operation tasks is a primary concern. The significance and implications of interface designs that respect human interaction parameters have been previously introduced with the discussion of vehicle operation provided in section 1.3.3. Embracing human centered designs and cognitive load management has allowed auto-makers to create machines that can be operated effectively in the most demanding circumstances and HCI engineers must seek the same level of design elegance.

Cognitive load has been an issue of concern in HCI research since the late 1980s. The term cognitive load refers to the mental resources a person has available for solving problems or completing tasks at a given time. Limited attention and working memory are the primary factors constraining cognitive load. Various researchers have developed new ways to avoid the negative effects of overtaxing interaction regimes by conspicuously managing the channels through which different stimuli are passed to and from the user. It has been shown that the best way to manage cognitive load is to reduce attention distractions and maximize working memory capacity.

Wickens et al.'s (1995) Multiple Resource Theory suggests that distributing the streams of stimuli between a computer and its user across multiple complimentary sensory modalities reduces the load and resource competition placed on individual processing centres of the brain.

The Fuse-Map interface embraces human-centered design and multiple resource theory by offering an interaction regime that manages cognitive load by separating discrete input and output flows across parallel sensory modalities according to task functions. This system reflects van Dam's (1997) descriptions of fourth generation, Post-WIMP human computer interface technologies, which use gesture recognition, speech interaction and **haptic** output technologies to simultaneously leverage many parallel yet complementary sensory channels.

Several studies have found that augmenting haptic and tactile interaction modalities with speech and audio feedback provides an enhanced learning environment for non visual users (Adelstein et al. 2003, Alonso et al. 2006, Jacobson 2004, Jeong and Jacobson 2002, Rassmus-Grohn 2006, Rice et al. 2005b). By assigning system control operations to verbal commands using speech recognition technologies the user's kinesthetic, somatic, and proprioceptive sensory channels can be entirely devoted to map exploration. For instance, when a user finds a point of interest on the map field and uses a voice command to hear the location of that feature, two separate sensory modalities have been utilized that complement each other without causing increased cognitive load or diverted attention. The users’ physical senses remain fixed on data exploration while the aural senses and speech channels can attend to interface operation and query tasks.

Creating a spatial data platform that allows bi-manual map exploration also expands the range of tasks that an interface can support in parallel without causing excess demands on the attention of a single sensory channel. When using the Fuse-Map interface, one hand can be devoted to exploration activities while the other is used for spatial referencing activities or to collect and place tangible markers and memory aids. For instance, a user's left hand could be used to find the position of a feature located under the right index finger in relation to the nearest point of interest, the map's border, or a known tactile marker. After finding a particular point of interest with the right hand, a user could pick up and place a tactile marker on that spot with the left hand. In each of these described instances both hands are assigned distinct tasks that do not interfere with each other.

5.1.2.3 Dynamic rendering from a refreshable display device

The ability to access many different files from a single computer is often taken for granted by visual computer users. Displays that create large, complex images from coloured pixels can easily provide dynamic streams of conspicuous content. However, replicating this feat with a non-visual display is not easily achieved. In these circumstances, unique mechanisms are needed to refresh some or all of the display output presented from moment to moment. Many tactile displays, such as those outlined in section 3.3.2.2, use motorized components to change the physical properties of a display's output by moving the position of representative 'bits,' such as pins or pegs.

Providing refreshable non-visual output that would allow many map scenes to be accessed from one terminal was a high priority objective in the Fuse-Map design. This interface has the ability to alter two different types of bits in order to refresh its rendered output. Firstly, the arrangement of audio features that are virtually projected across the display field can be altered from scene to scene. Many different soundscapes of spatially portrayed data can thus be output through one terminal. Secondly, the arrangement of 'taxels' produced by the magnetic tactile display can also be refreshed and altered to create new tactile patterns from scene to scene.

One critical decision also made for the Fuse Map's operation was to prioritize the provision of content streams that change intermittently, as opposed to continuously. A continuous refreshable dynamic display, such as a television or computer monitor, is able to change its output so rapidly that the resulting image appears to be in continuous uninterrupted motion. This effect may be used to create animated imagery and full motion video. Without a synoptic sensory system to detect and track changes across rapidly refreshing content, non-sighted users may become easily disoriented and unable to follow the flow of data. Furthermore, creating a system that only changes its output when prompted by the user supports the requirement for a system that continuously informs the user of its state of operation (affordance 4.3.3.4).

5.1.2.4 Reality based interactions

The use of RBIs makes computer interfaces with tangible and haptic modes of interaction more intuitive by linking the tasks that a user intends to perform on their computer to the way a similar task would be performed in real life. RBIs employ themes of reality based upon user's understanding of naive physics, their own bodies, the surrounding environment and other people.

(Jacob et al. 2008, Solovey et al. 2009).

Two themes that characterize the experiences of non-sighted people are experiences of the world through touch and physical space, and experiences of the world through sound and speech. Both of these themes are reflected in the Fuse-Map's design approach for information representation and interface operation.

The ability to touch and manipulate tangible objects near one's body provides a direct stream of stimuli about the world and there are many ways to interact with the immediate environment in this fashion. The tangible attributes of an object or environment can be inspected at arm's length, with the hands or fingers by pressing, grasping, shaking, lifting, turning, holding, sliding and rubbing (Figure 3.11). The Fuse-Map interface leverages these actions for certain map exploration tasks to provide a form of interaction that mimics how non-sighted users may interact with other non-digital items. Examples of natural and intuitive reality based interactions that could be used in this context include: finding new features in a map based on changes in physical qualities like friction or surface elevation, tapping a map feature with a finger to select or activate it as if one were pressing a physical button, and placing a tactile marker on a desktop surface as if moving a token on a board game. An individual's proprioceptive awareness of their own body position can also be used to create an artificial frame of reference for a tactile display. Features that are found on a tactile display away from a user's body are understood to be more distant within the map's frame of reference than features that are found closer to a user's body.

Experiences of the world through sound and speech draw upon human language exchange and meaningful non-verbal sounds to create salient information representations and task commands that can control the operation of a computer system. Direct interactions between people can take many forms outside the digital realm but verbal conversations and attention to environmental sounds are the most powerful. The Fuse-Map interface uses audio playback as a form of data output and speech interaction as a form of user input. The user can talk to the computer system, in a limited fashion, in the same way that they would talk to another person to ask questions and give instructions. By providing meaningful audio responses the computer gives a form of feedback that mimics the aural qualities of an authentic soundscape or conversation exchange. For instance, the user can ask the computer questions like "Where am I?" or "What is this?" in order to find out the location and identity attributes of a feature under their exploration finger.

5.1.2.5 Memory Aids and Mark-up Functionality

There are many skills and abilities that enable individuals to modify and manipulate the physical and referential properties of objects in their environments (Solovey et al. 2009). A person may flip, fold, write on, cut, stack or tear a piece of paper so that it is better suited for an intended purpose. Since the human brain possesses a limited working memory capacity, these actions are often used to mark or modify an object so that particular attributes are emphasized for fast recall and identification. Skills that manipulate objects for the purposes of memory augmentation and information organization are reality based interactions that can be used with great effectiveness in spatial data platforms.

The data presentation output of a human computer interface like the Fuse-Map interface can be much larger than the **spatial memory** capacity of a human user. However, memory aids and map mark-up tools can be used to extend and augment spatial memory so that complex or comprehensive exploration and analysis tasks can be completed. Assistance features of this sort may be physical or virtual and can be predefined by the data set's author or by the interface user. Gutwin and Anton (2006) list bookmarks, target prediction tools and history mechanisms among the methods that are often used to help users find and relocate objects in virtual workspaces.

The Fuse-Map interface relies primarily on tactile markers to provide memory assistance and mark-up functionality to users. The use of magnetic fields as a form of spatial data output is also conducive to token based feature tracking. This format for memory assistance enables users to place objects, such as metallic tokens, directly onto the display field in order to mark the location of an identified point of interest (Figure 5.5). Since the magnetic fields created by the Fuse-Map's display device extend through the display surface and marker, the physical properties of the output feature and the token object can be sensed simultaneously. This method of memory assistance is akin to circling a feature or placing a pin onto a paper map and utilizes the phenomenon of tactile transparency that is described in section 5.1.2.1. Kildal and Brewster's (2007) experimentation with the use of virtual memory aids in a spatial data display provided two requirements for this type of interface functionality. First, the complete dataset must be continuously displayed so that information can be found when a marker is revisited. Secondly, the tangible borders of the display must correspond directly to the virtual boundaries of the map scene so that marker's position remains consistent with the arrangement of the spatial data.

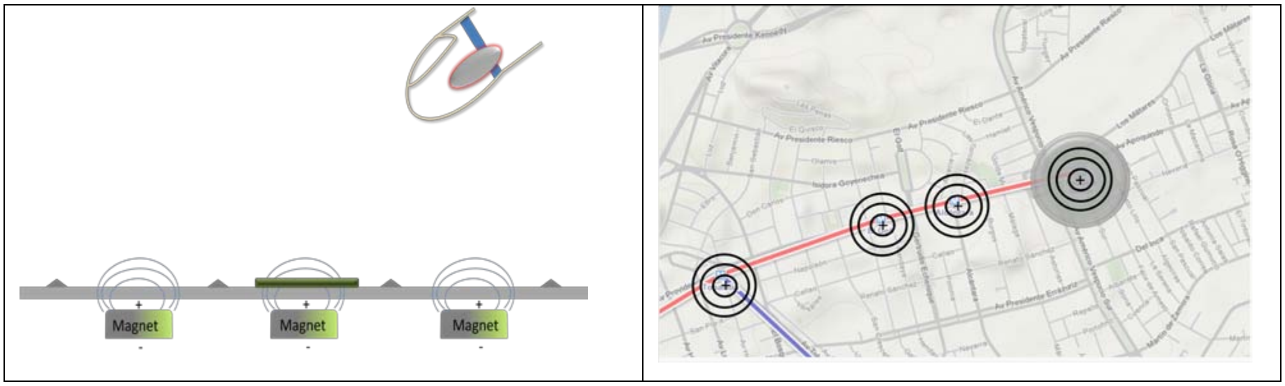


Figure 5.5 (Left) Metallic tokens, such as a coin or metal disc, can be held in place by magnetic fields passing through the substrate of a near-surface haptic display. These tokens can be used as physical memory aids to flag features of interest within a spatial data scene (Right).

5.1.2.6 ***Integrated Software Agents and Spatial Analysis Tools***

Spatial analysis tools allow users to derive new information from existing spatial data. Spatial data is often used in decision making and problem solving contexts to achieve an optimal solution for a desired goal. Many of the computer products that process and handle spatial data for these reasons do not just present and display geographic images, they also provide tools and features that allow for more intricate and complicated spatial queries and statistical summaries to be performed. Examples of these processes could include determining what path between points avoids certain obstacles, identifying where clusters of features occur, calculating the total size of a particular map feature, or selecting the best location for an activity based on multiple attributes.

Software agents are sub-programs within an application that perform tasks on a user’s behalf, such as auto-saving a document, spell checking text, logging the flow of changes to a document to allow steps to be undone, or automatically adding metadata like the author’s name and the current date to a document when it is edited.

By providing spatial analysis tools and integrated software agents computerized spatial data platforms act as an assistant to the user. For blind and visually impaired users, the provision of software agents and spatial analysis tools in an accessible spatial data platform can be a significant benefit. The ability to offload tasks that would otherwise require visual attention onto a computer decreases personal cognitive load during map use and increases task productivity.

5.2 Hardware

The configuration of the Fuse-Map prototype is based upon a personal computer with a variety of input and output devices. Figure 5.6 outlines this configuration.

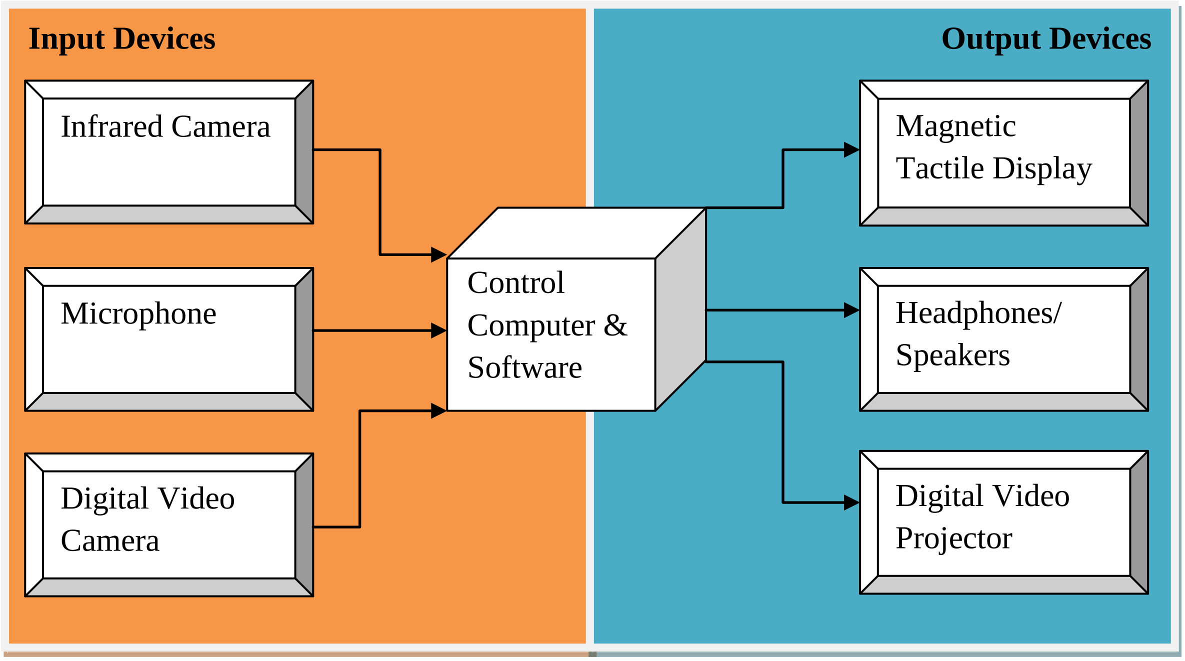


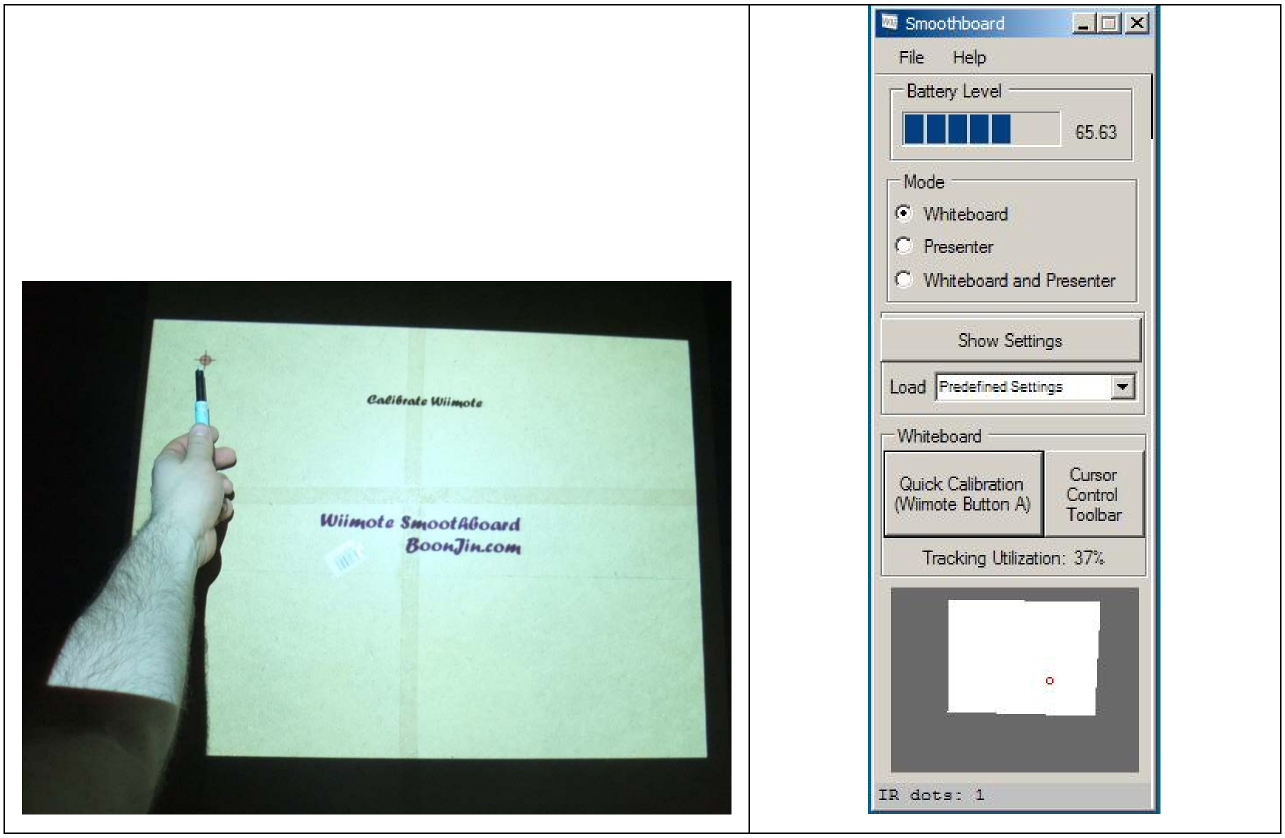
Figure 5.6 Input/Output schematic of the hardware components used in the Fuse-map interface.

5.2.1 Input Devices

5.2.1.1 Computer vision system

The Fuse-Map interface’s primary input device is a computer vision apparatus used for tracking the movement and position of the user’s hands within the map scene. For the first generation prototype of this interface a Nintendo Wii (Nintendo 2012) remote served as the camera device and captures data for the computer vision protocol. This remote uses an infrared sensitive camera that is normally used to track its own motion relative to a fixed reference point: the Wii Sensor Bar. However, in the configuration used for the Fuse-Map interface, the Wii Remote is mounted vertically with its field of view aimed at the magnetic display situated on the desktop surface below. A calibration utility was used to determine the extent of the tracking space within the display boundaries (Figure 5.7). In this way an XY coordinate system was defined that can be referenced to the boundaries of the virtual map scene.

Mounting a battery powered infrared LED on top of the user's finger provides a point of light that can be identified by the Wii remote camera. When the point of light on the user's fingertip enters the tracking area its coordinates are transmitted to the computer and used to plot the movement of a cursor across the map scene. The user's finger effectively becomes the "mouse" used to control cursor movement, just as it would be if a track pad or touch surface were used. One advantage of this system is that the hand maintains an absolute frame of reference within the map boundary, rather than the relative frame of reference that traditional mice and track pads provide. By locating all the hardware used for hand tracking above the user's hand other hardware, such as the magnetic display device, can be embedded below the desktop surface where touch sensors would normally be installed.



Battery Level
65.63

Mode
● Whiteboard
○ Presenter
○ Whiteboard and Presenter

Load Predefined Settings

Whiteboard
Tracking Utilization: 37%

IR dots: 1

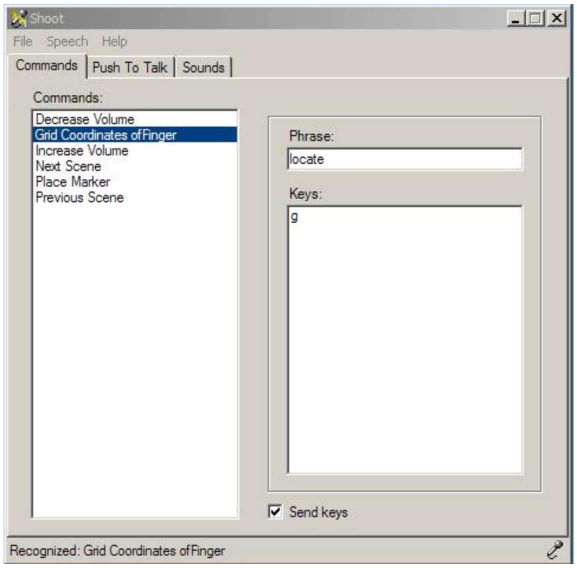
Figure 5.7 Calibration of the Wii remote tracking field (Left). The Wiimote Smoothboard software identifies an IR tracking dot within the tracking field and converts its movement to cursor movement. (Right)

5.2.1.2 Speech Input

The second input system used in the first generation Fuse-Map Interface is a basic speech recognition system. This system affords direct control over the interface's operation using customizable verbal commands. A wireless headset is used to provide a microphone that the user can speak into. Shoot (Traverso 2004), a program originally designed for computer gaming purposes, virtually translates recognized spoken words and phrases into keyboard commands and keystrokes. This program listens for and identifies speech content picked up by the microphone and then outputs specific keystroke values when defined words are recognized (Figure 5.8). Table 5-1 lists some commands that were implemented to test the Fuse Map system. For testing purposes, Shoot was also configured to play a sound to confirm that a verbal command had been recognized. This provides the user with valuable awareness of the system's operation state.

Commands	**Keystroke**	**Associated Functionality**
Locate	G	Speak the locate of the tracked finger
Place Marker	P	Place an audio marker in at this location in the map scene
Increase Volume	+	Increase the interface's sound volume
Decrease Volume	-	Decrease the interface's sound volume
Next Scene	N	Go to the next map scene
Previous Scene	B	Return to the previous map scene

Table 5-1 Commands and associated tasks used for speech recognition in the Fuse-Map interface



Commands:
Decrease Volume
Grid Coordinates of Finger
Increase Volume
Next Scene
Place Marker
Previous Scene

Phrase: locate

Keys: g

☑ Send keys

Recognized: Grid Coordinates of Finger

Figure 5.8 Screen capture of the Shoot application. A command prompting the audio playback of a user's finger location has been recognized.

5.2.1.3 Video recording equipment

Audio/Video recording hardware was integrated into the laboratory version of the Fuse-Map user interface design in order to facilitate *ad hoc* observations of user behaviours, experiences, and interface events during and after testing sessions. The video recording equipment used recorded users from a top down perspective (Figure 5.9) and an oblique perspective while they were using the Fuse-Map interface. Analysis of the recorded output of this equipment allows the investigator to assess many different aspects of user behaviour by comparing, characterizing and quantifying the counts, streams and sequences of interface events (Hilbert and Redmiles 2000).

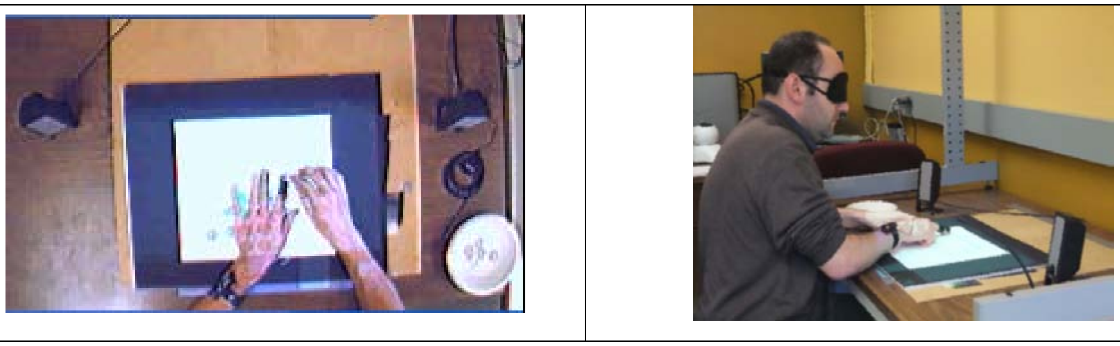


Figure 5.9 Video recordings of Fuse-Map users from overhead and oblique perspectives.

5.2.2 Output Devices

5.2.2.1 Magnetic Display

The magnetic tactile display designed for the Fuse-Map interface consists of a 25cm x 25cm array of switchable pixels that place rare earth magnets in a 8x8 grid on the underside of an acrylic plate. The boundaries of the display are physically marked by a layer of cardboard matte.

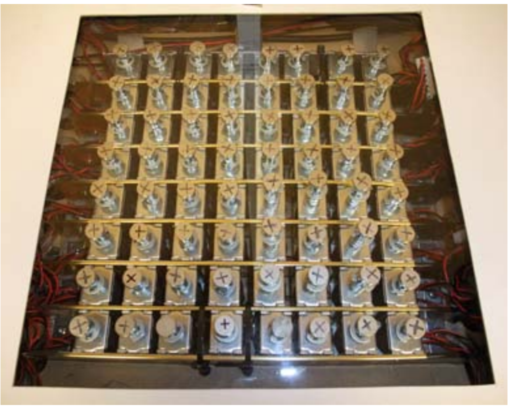


Figure 5.10 The Fuse-Map interface's magnetic tactile display device.

To sensitize the user to the magnetic display, a flexible metallic layer must be attached to the pad of a finger. This is achieved by coating the fingertip with a thin layer of liquid latex, bonding iron particles to this base layer and then sealing the iron layer with a second top coat of latex

(Figure 5.11). Once the latex/iron patch has cured the user will be able to detect a very distinct tugging sensation when the coated fingertip passes over a magnetic point. After use the latex/iron pad can be removed from the fingertip by simply pressing it against the opposing thumb and rolling it away from the skin. An alternate method for achieving magnetic finger augmentation using latex and an iron moulded as an adhesive bandage has also been tested with reasonable success; however this method does not maintain the sensory fidelity of the process described above. Several other procedures for affixing a magnet or metallic apparatus are described by (Weiss et al. 2011a)

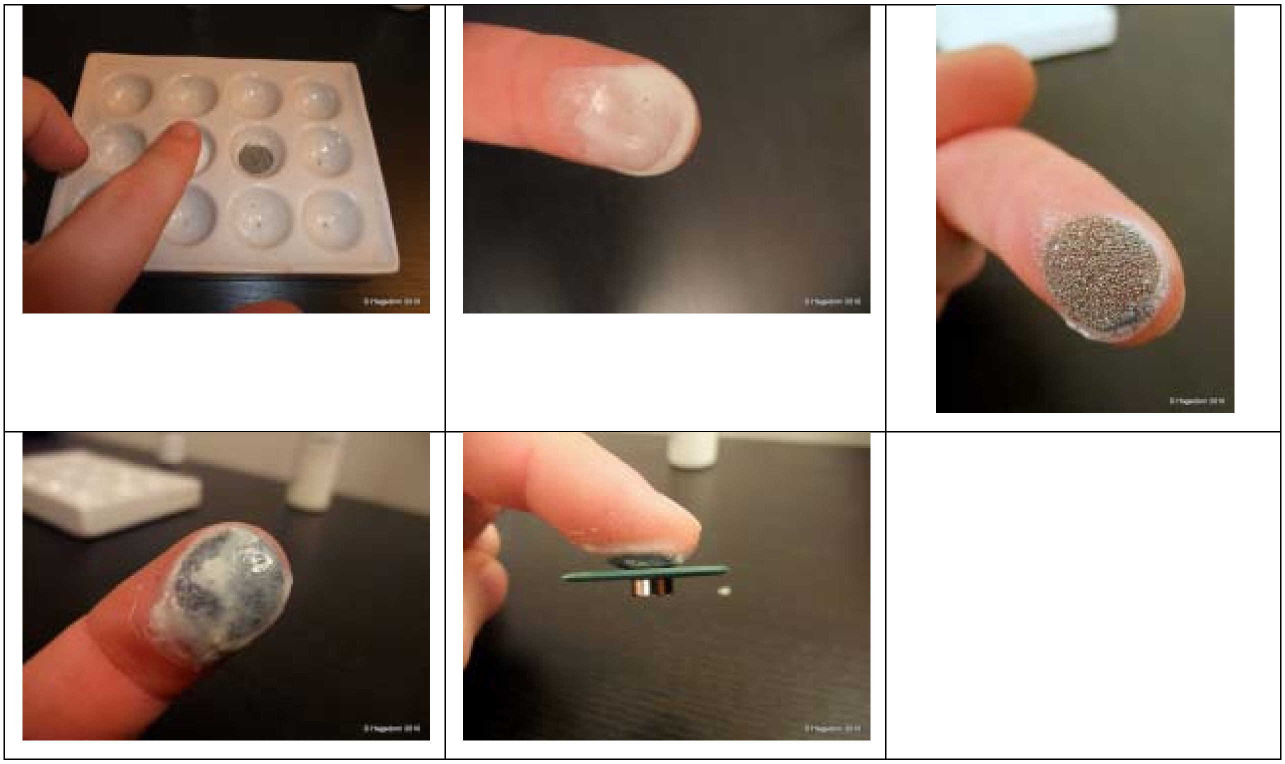


Figure 5.11 The application of liquid latex and iron filings to the tip of the finger quickly and easily provides a way to detect magnetic fields.

5.2.2.2 Digital Video Projection

The Fuse-Map interface utilizes a digital video projector to provide high contrast visual output. The provision of visual output supports multi-modal rendering as recommended in section 4.3.1.1. A visual output channel serves the needs of visually impaired users who may have some degree of residual vision. It also facilitates multi-participant collaboration between sighted and non-sighted users who wish to work together while using the Fuse-Map interface. Finally, visual output is beneficial when the interface is used in an experimental laboratory setting as it allows researchers to observe the map objects that users are interacting with. Like the computer vision apparatus, the digital video projector used to provide visual map output is mounted above the magnetic display surface. This locates the projected screen space within the boundaries of the map field and creates an image that is not obscured by anything placed on the desktop surface, such as memory aids or the user’s hands.

5.3 Use Examples of the Fuse-map Interface

The Fuse-Map interface’s universal design approach allows this system to be widely used in a variety of different contexts. The following examples briefly describe different ways this platform can provide value to non-sighted users and their peers in academic, professional, and domestic contexts. The ability to both access and create digital content that the Fuse-map interface affords is imperative for school and workplace activities where individuals are often required to work collaboratively and share documents and resources among a team of people.

Modern educational policies mandate that inclusive learning environments should be created in schools so that all students can access learning materials and lessons. Teachers frequently provide students with study materials about spatial concepts, such as diagrams, maps, tables and graphs. Traditional methods for creating non-visual study materials like tactile maps and Braille documents can be difficult and time-consuming for teachers, particularly for those who do know Braille well or who are constrained by limited budgets. The Fuse-Map interface could be used to replace a variety of tactile maps and Braille products created for different subjects. For example, it could be used in lieu of tactile maps depicting the locations and attributes of capital cities, the structure of chemical compounds, the periodic table of the elements, the products of mathematical equations, or nutrition guidelines (Figure 5.12).

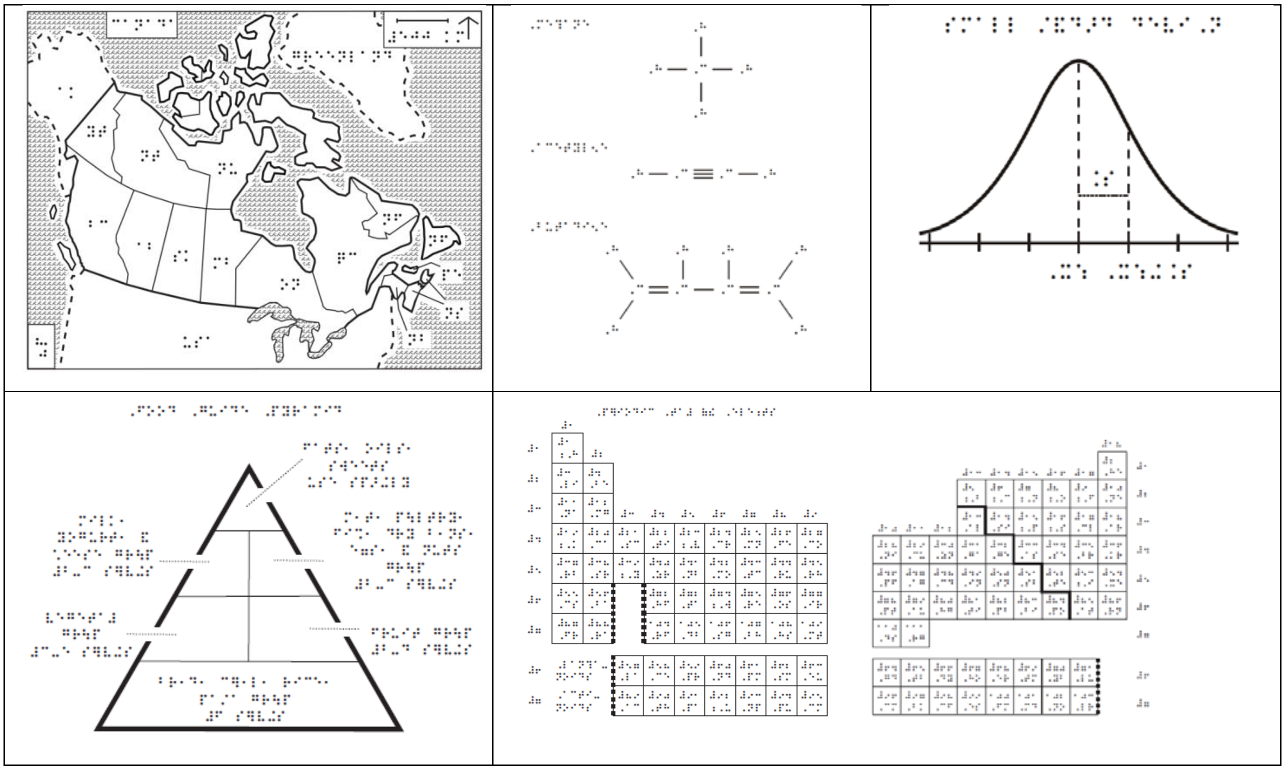


Figure 5.12 Examples of classroom lesson materials commonly presented using static tactile maps. Top Left- The Tactile Atlas of Canada (NRC 2002b). Top Middle – Molecular structures for methane, acetylene, and butadiene. Top Right – A normally distributed data set. Lower left – The USA Nutrition Guidelines Pyramid. Lower Right – The periodic table of the elements. (AFP 2012)

Students using Fuse-Map interfaces both at home and at school can easily save and download digital files from either place to complete assignments after class. This is preferable to transporting bulky and fragile tactile maps in a backpack. The digital nature of Fuse-Map content also allows students of any language background to access classroom content using computer based translation utilities, which again saves time and effort for teachers and students. Multi-modal output also allows students to participate in collaborative learning exercises where one student may see on screen what another explores with his or her hands and ears.

In a professional setting, the Fuse-map interface could be used to provide non-sighted workers with a better awareness of a company’s physical resources, client details, project sites and corporate documents. These include corporate organization charts, office layouts, company websites, product schematics, and financial figures.

There are many ways that a non-sighted person could use a Fuse-Map interface in domestic contexts. Finding and sharing directions for travel to and from home is one of the most valuable applications of the Fuse-Map interface. Many bus, subway and train maps that use point and line information structures can be easily rendered with this technology (Figure 5.13).

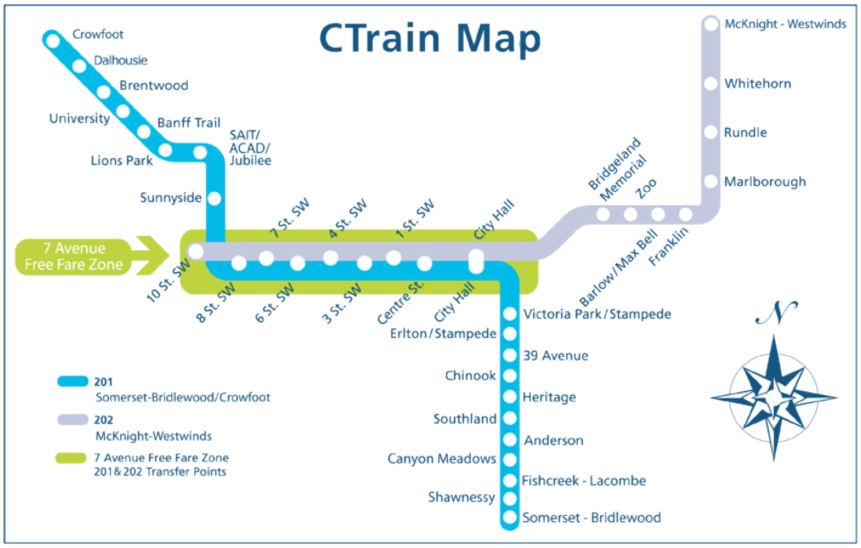


Figure 5.13 A Transit Map illustrates point and line style spatial data information structures that can be represented relatively easily using the Fuse-Map interface (COC 2012).

Gaming and leisure activities represent another application where the Fuse-Map interface can provide value to non-sighted users at home. Various board games and arcade games that rely on spatial representations could be directly ported to the Fuse-map interface. Musical notation, which is also highly spatial in many respects, could be displayed on the Fuse-Map interface to help non-sighted musicians conveniently catalogue and write their repertoire of songs.

5.4 Conclusion

The Fuse-Map interface's unique system architecture, design specifications and potential applications provide an innovative new way for non-sighted people to access and create spatial data. This system integrates the desirable affordance features identified in chapter four and builds upon dominant technology trends found in other areas of HCI research. These features include computer vision based body motion tracking devices, interactive touch surfaces, speech recognition and rich/intelligent audio feedback, dynamic tactile and haptic output, bi-manual gesture and artifact based content manipulation techniques, and reality based interactions.

The emergence of these nascent technologies has just recently provided the building blocks for interface design concepts like the Fuse-Map interface. Only the first possible manifestations of this new research direction have yet been seen and future technical innovations, technology combinations, and design refinements will likely change the parameters of this system significantly. The evolution of this interface will progress as future user feedback is collected and the capabilities of a system like this one could inspire many new and unanticipated technologies. The Fuse-Map interface should, therefore, be seen as the first inventive but crude step towards what could be a long evolution for accessible multimodal spatial display platforms.

In comparison to the current best practices for rendering spatial data in accessible multi-modal formats, the Fuse map system has several evident strengths. Table 5-2 compares this system's essential design features with alternate mapping technologies used by non-sighted people.

The overall goal of the Fuse-Map interface's design has been to create a platform that provides levels of spatial data accessibility and utility to non-sighted people that are as equivalent as possible to what is available for sighted users. Although this interface product represents a potential step forward, significant design refinements are needed before that goal is achieved. Limitations that must still be addressed include issues of data representation scale and resolution, data file-type standardization, symbology diversification, and content authoring methods.

The magnetic tactile interface used in Fuse-Map interface prototype currently has a far lower output resolution than many other technologies, which limits its rendering abilities to very coarse imagery. Compared to modern computer screens that can provide dynamic output resolutions of many thousands of pixels, an 8x8 pixel resolution is insufficient. While the ultra-high resolution provided by visual displays may not be needed or beneficial for non-sighted users, certain cartographic techniques, such as rendering unbroken lines or whole polygons require pixel densities higher than what the Fuse-Map interface can currently offer. This is especially true if the system is intended to natively display data files created from other GIS products.

Properly demonstrating the utility and viability of the Fuse-Map interface will require evidence that spatial learning can be independently achieved by users. This evidence must demonstrate that the interface's unique features facilitate clear information uptake from data representations and the ability to create new spatial data representations that match a user's intentions without distortion. Demonstration activities intended to evaluate user experiences, mapping functionality and the overall learning potential of the Fuse-Map interface are addressed in chapter six.

	Support for Transparency Effects	**Functional Separation**	**Dynamic Output**	**Reality Based Interaction**	**Memory Aids and Mark-up Tools**	**Spatial Analysis Tools and Integrated Software Agents**
Fuse –Map	Yes	Yes	Yes	Yes	Yes	Yes
Static Tactile Maps	No	No	No	No	No	No
Tangible Computer Interfaces	No	No	Yes	No	No	No
Touch Sensitive Computer Interfaces	No	No	Yes	No	No	Possible
Motion Capture Devices	Yes	Yes	Yes	Yes	No	Possible
Exoskeleton Style Haptic Devices	Yes	No	Yes	Yes	No	Possible
Tool Handling Haptic Devices	No	No	Yes	No	Possible	Possible
Object Oriented Haptic Devices	No	No	Yes	Yes	Yes	Possible
Auditory Interfaces	Yes	No	Yes	Yes	No	No
Haptic Soundscape Devices	No	No	Yes	No	No	Yes
Virtual Reality Devices	Possible	No	Yes	Yes	Possible	Possible
Near Field Haptic Devices	Yes	Possible	Yes	Yes	No	Possible

Table 5-2 Essential Design premises provided by the Fuse map interface in comparison to alternate non-visual spatial data platforms. Items listed as possible may require complementary technologies or atypical software/hardware adaptations.

6 Functional Demonstration

In order to explore the functionality of the Fuse-Map interface a set of demonstration activities and diagnostic trials was devised. The results and observations obtained were used to determine if this system can actually provide non-sighted people with access to maps and digital geospatial data, as per the main objective of this thesis. The first demonstration activity gauged spatial data representation functionality and the second activity assessed data editing functionality.

A purpose built Fuse-Map interface and work station was created for these activities. This interface, shown in Figure 6.1, accommodated both the participant and researcher and integrated the hardware and software needed to run and observe these activities. Participants using the Fuse-Map interface were observed individually while seated on a rotating chair in front of a desk upon which the interface was placed (A). Diagnostic instruments were placed on a table located to the user's right that could be reached by rotating the chair 90 degrees (B). The researcher and control computer were then situated at a second desk to the right of the interface on the other side of the diagnostic table (C).

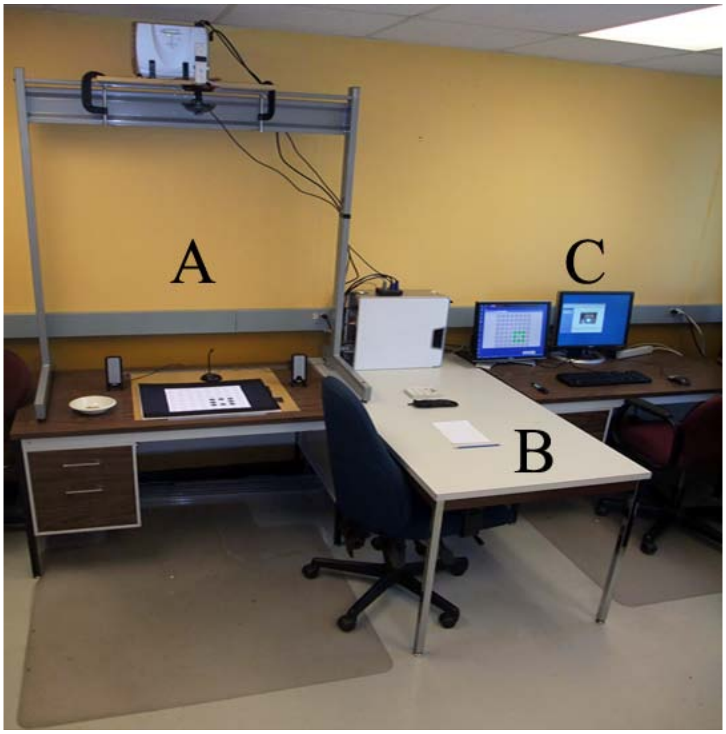


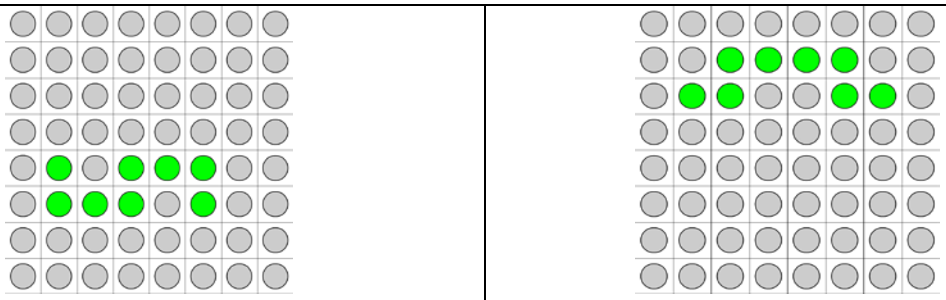
Figure 6.1 A Fuse-Map interface workstation created for user testing purposes.

6.1 Demonstration Activity One – Spatial Data Representation

6.1.1 Demonstration Procedure

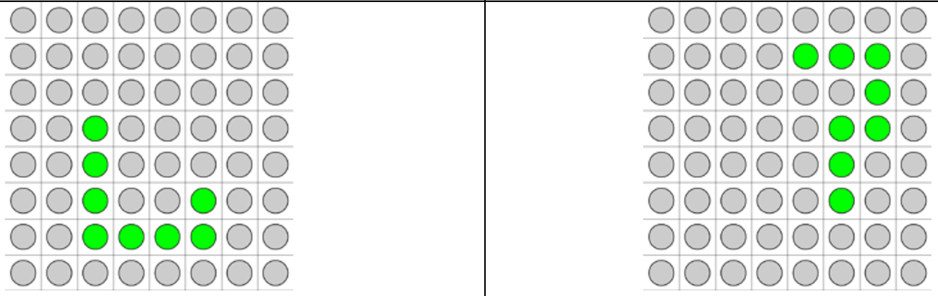
To complete the spatial data representation activity, a group of ten users with vision loss simulated via blindfold used the Fuse-map interface to locate a pattern of target points in simplified interactive map scenes created with Adobe Flash software (Adobe 2010). Each map scene consisted of sixty four virtual feature points projected onto an eight by eight grid of rare earth magnets. Eight adjacent points were selected to create the target pattern in each scene and the remaining fifty six points were left as neutral features. Each point behaved as a virtual button that played a defining sound when a touched by a user’s IR tracked finger. Points that were part of the target figure played a bell tone when touched while points that were not part of the target figure made a simple clicking sound when touched. A training scene was also created to teach users to differentiate target and neutral features without sight (Included in Digital Appendices).

Six unique map scenes were divided into three exploration conditions with two scenes each (Figure 6.2). When exploring the first and second maps scenes for the first exploration condition, users received no additional feedback to determine the location of the target points they encountered other than their own sense of hand position and the sound tag of each point. In the second exploration condition, users could speak a verbal command to prompt the computer to announce the location coordinates (i.e. A1, A2, A3, A4, A5, A6, A7, A8, B1, B2…H6, H7, H8) of their IR tracked finger. In addition to the audio coordinate feedback feature introduced in condition two, users were also then asked to place a 25 cent coin wherever a target point was identified in the third condition map scenes. These coins served as tactile memory aids or feature markers that could be held in place on the map surface by magnetic pixels. Specific information about the map scenes being explored, such as the number of points in each target pattern, was only provided when directly requested by the participant. This approach was taken to mimic the metadata query functionality found in a standard GIS.



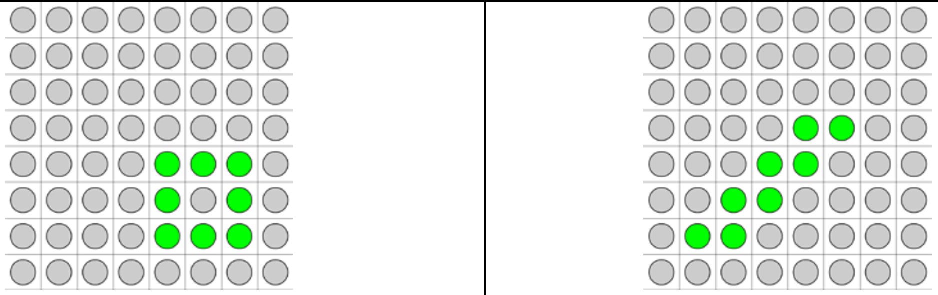
1A - Condition One – Pattern One

1B - Condition One – Pattern Two



2A - Condition Two – Pattern Three

2B - Condition Two – Pattern Four



3A - Condition Three – Pattern Five

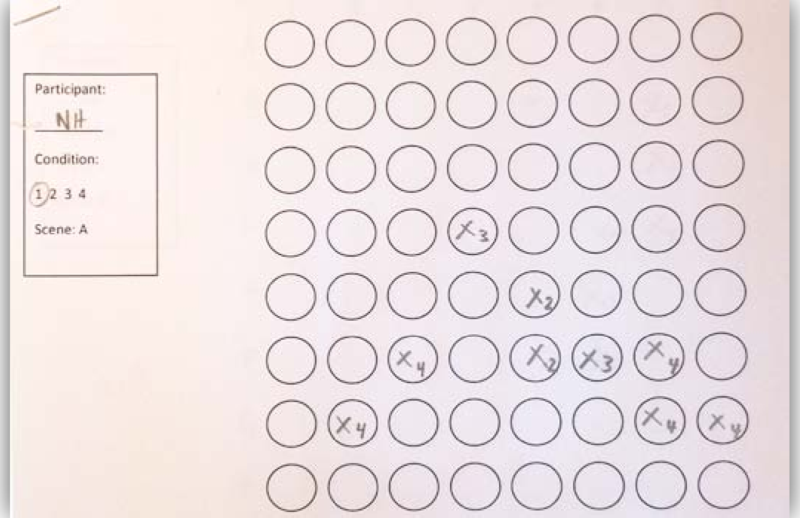
3B - Condition Three – Pattern Six

Figure 6.2 Six map scenes containing unique target feature patterns were explored by demonstration participants using the Fuse-Map interface.

Condition One	Scenes one & two	No Assistance Features Available
Condition Two	Scenes three & four	Grid coordinates available via synthesize speech
Condition Three	Scenes five & six	Tactile memory aids and spoken grid coordinates available

Table 6-1 Maps scenes and assistance features associated with three exploration conditions defined for demonstration activity one.

After every exploration session, participants were asked to remove their blindfold and complete a cued-sketch diagnostic test to assess their success. Participants marked an X in pencil at target locations on a diagram of sixty four circles replicating the eight by eight grid of magnetic pixels and virtual buttons (Figure 6.3). They were also asked to rate their confidence for the location accuracy and identity of each target point drawn on the cued sketch using a one to five scale, with one indicating a low degree of confidence or a guess about the point's location and a five indicating absolute certainty. Cued Sketches are recommended by Kitchin and Jacobson (1997) as a way to assess a survey knowledge about features within a defined frame of reference.



Participant: NH

Condition: [✓ 1] 2 3 4

Scene: A

Figure 6.3 A completed cued sketch recreating target points from map scene 1A.

6.1.2 Data Recording and Observations

In addition to cued sketch sheets, observational data from each participant demonstration of the Fuse-Map interface were collected with three different methods: participant and researcher observations, video recordings and photos, and recorded finger tracking.

6.1.2.1 Researcher Observations:

Notes and personal observations were collected by the researcher throughout the Fuse-map demonstration activities. These notes capture comments made by participants using the Fuse-Map interface, observed difficulties or successful user exploration strategies, as well as comparisons to other participant trials. The results of each exploration session were not discussed with participants until after all six map scenes had been presented when a debriefing discussion could be carried out. These discussions proved to be a significant source of insight as participants reflected on their personal experiences using the system most at this time.

6.1.2.2 Video Recording and Photos:

Video recordings and photos of every user trial were made to observe and revisit participants' overall interaction tendencies with regard to exploration strategies, difficulties, habitual behaviours, timing, posture and ergonomics (Figure 6.4). An overhead video camera was used to observe users' hands in relation to the displayed map scene. The video output was viewed on screen next to the system's mapping software interface and recorded as a screen capture movie. User photos were also taken to record specific user interactions and the overall progress of the demonstration activities. A photo was taken after each exploration session using memory aids to capture the final location of each coin. These photos were used to compare users' figure recreations to their exploration outcomes.

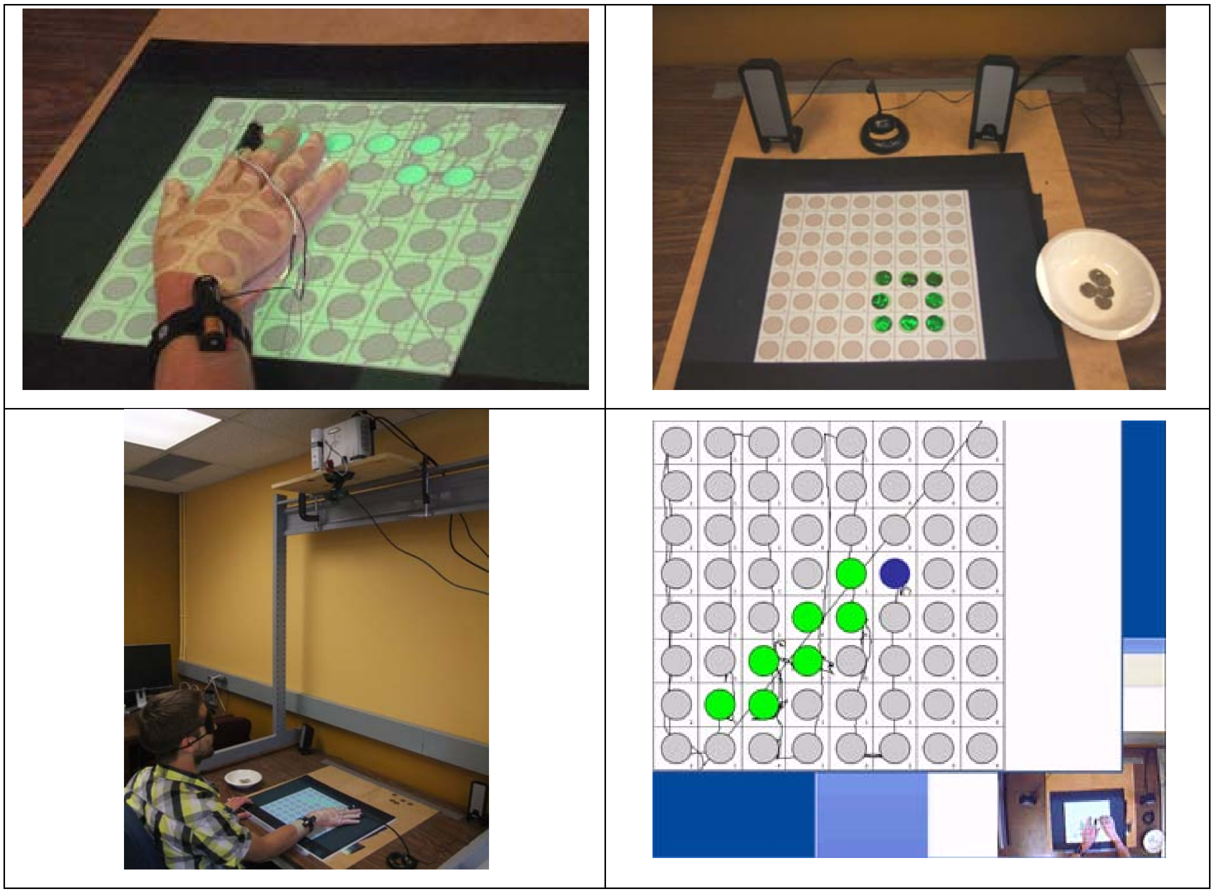


Figure 6.4 Top Left - A user encounters a target point. Top Right – An arrangement of coins placed to mark the location of target points in map scene 3A. Lower Left – A user exploring the boundaries of the magnetic tactile display. Lower Right – Overhead video recording of a user's hands exploring the Fuse-Map's magnetic tactile display.

6.1.2.3 Cursor capture and software behaviour:

The software instrument created for the Fuse-Map demonstration activities was also programmed to trace and capture the movements of the user's virtual mouse cursor throughout the map scene exploration process. Data from this capture was output in three different ways: as a time referenced movement log (Figure 6.5), as a trace image (Figure 6.6), and as a video replay.

days	hr	min	sec	km	m	cm	keystrokes	left button	right button	middle button	double clicks	speed (km/hr)
0	0	3	34	0	2	86	18	3	0	0	0	0.11

Figure 6.5 A time referenced cursor movement and keyboard event log .

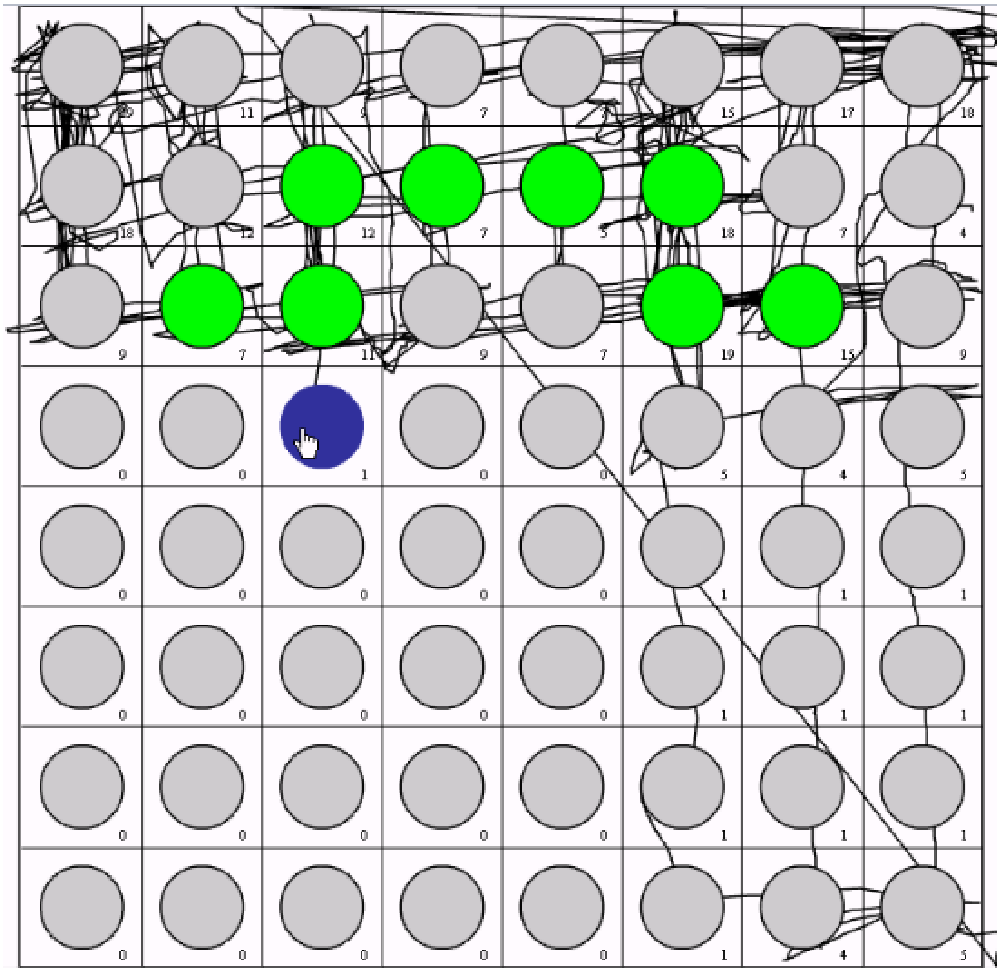


Figure 6.6 A participant's finger movement trace image from map scene 1B.

6.1.3 Demonstration Results and Discussion:

6.1.3.1 General observations:

The overall results obtained from the first Fuse-map demonstration activity suggest that this interface concept can be used as viable means for people who lack sight to perceive and understand abstract representations of digital spatial data. In total, 20 out of 60 scenes recreated by the demonstration participants were completed without any errors and a very high degree of confidence (Figure 6.7). Another four scene recreations were also completed that included all points of the target patterns in their correct locations, but also included one or more additional false positive points. It is worth noting that the confidence ratings in the scene recreations containing false positives were much higher for the correct target figure points than those for the additional unnecessary features. The distribution of the twenty correctly completed test scenes also suggests that the addition of assistance features (coordinate announcements and tactile memory aids) does induce better rates of information perception and uptake. The first condition only had one total correctly recreated scene, while the second and third condition had eight and eleven correct scene recreations, respectively.

Basic quantitative observations also suggest a positive relationship between practiced use of the Fuse-Map interface and successful spatial data uptake. On average the overall configuration variance of target points plotted in cued scene recreation sketches decreased significantly from users' first to last exploration session. Configurational distortions also became much less severe with each subsequent scene recreation.

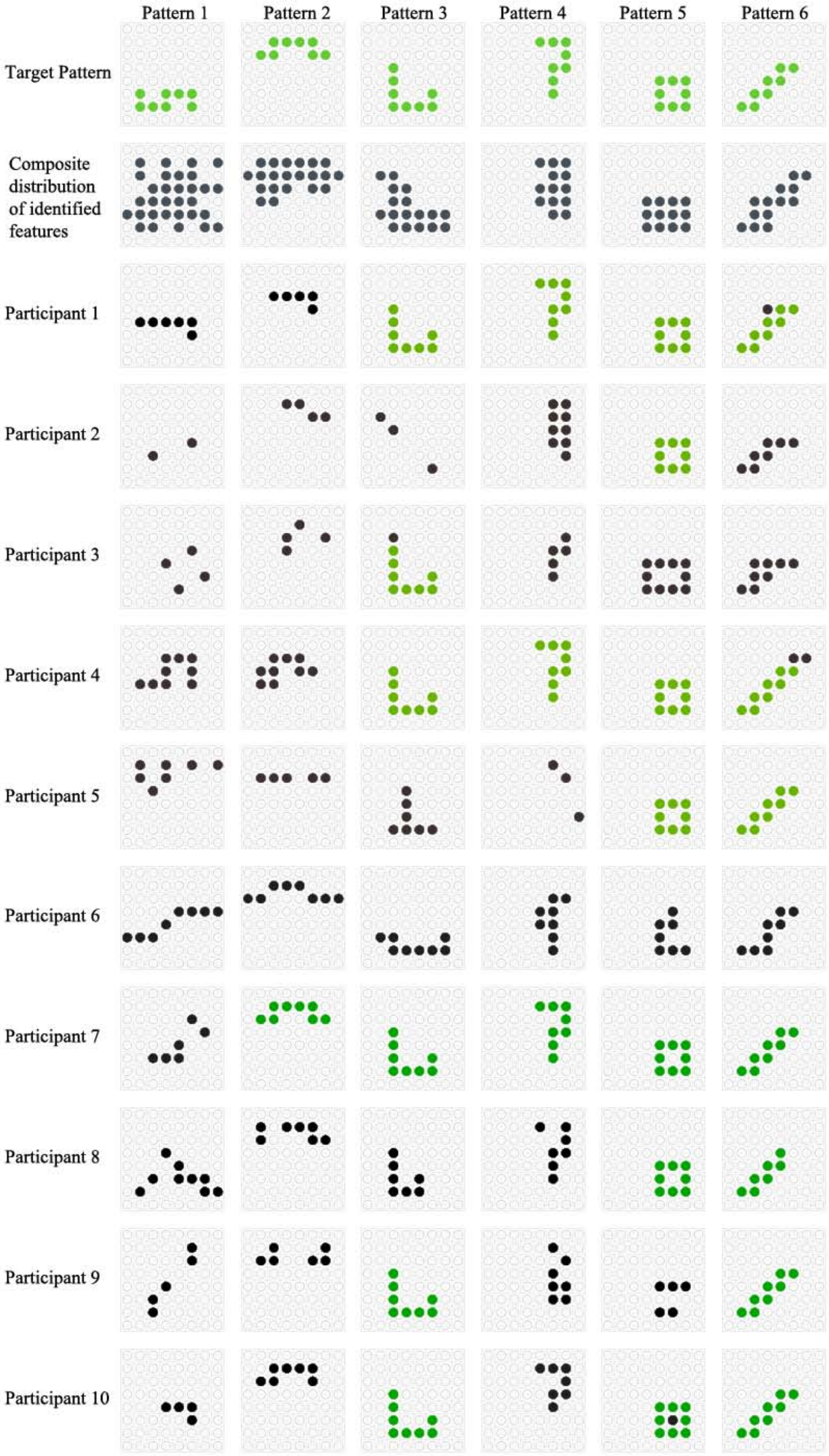


Figure 6.7 A summary of sixty cued sketch recreations created by ten demonstration participants. Point patterns that were correctly recreated are shown in green. The top row of figures shows the correct target pattern and the second upper row shows the cumulative distribution of points plotted for each pattern.

The obtained results indicate a strong positive relationship between the addition of the Fuse-Map interface's unique assistance features and increased exploration accuracy, completeness and confidence. Researcher observations and anecdotal reports from participants indicate that the addition of audio grid coordinates helps increase perceptual accuracy for spatial features, while the addition of tactile memory aids helps increase exploration completeness.

In addition to perceptual accuracy and exploratory completeness, confidence levels were also elevated for the second and third conditions compared to the first. Aggregate average confidence reports the total number of points identified for both scenes in each condition divided by the total confidence tally of all points reported for both scenes in that condition. Condition one provided an aggregate average confidence score of 3.62, compared to 4.55 and 4.53 for conditions two and three, respectively. Mentally cross-referencing the feedback provided by these two assistance features, in combination with proprioceptive sensory cues, seems to help increase confidence by relating multiple factors to draw more certain inferences about a feature's properties.

Trends in user's overall confidence rankings for each pattern also show a positive relationship between advanced use of the Fuse-Map interface and elevated spatial awareness for each scene. Figure 6.8 and Figure 6.9 illustrate how users' reported confidence levels increased in tandom with figure accuracy. The number of users reporting a high degree of confidence for points placed in the correct location increased dramatically between Scene 1A and Scene 3B. This trend is also expressed in relatively low confidence rankings for points placed incorrectly in scene recreations where most other points are known to be correct. Figure 6.9 shows that the concentrations of points placed in correct location also corresponds to higher reports of confidence at those locations.

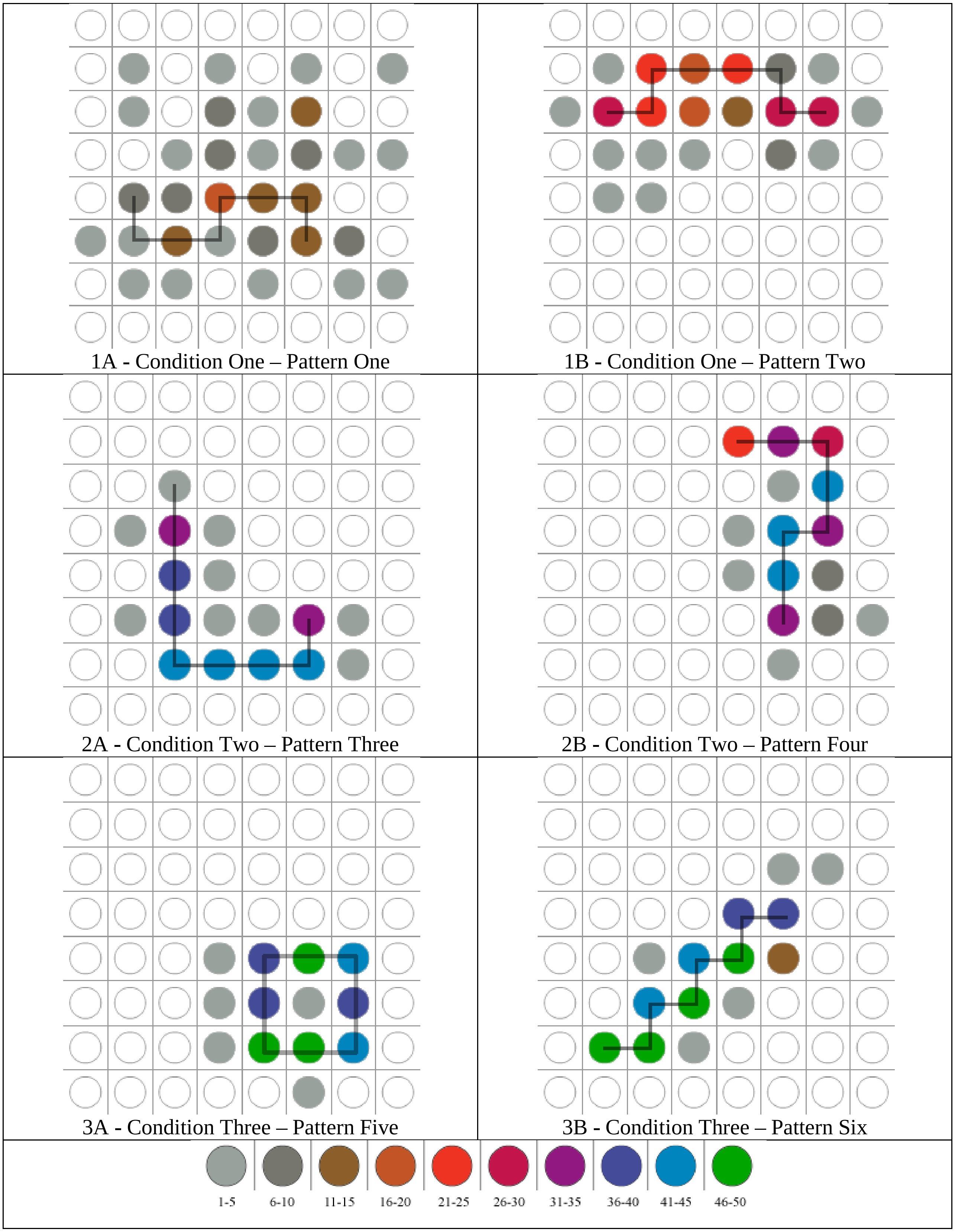
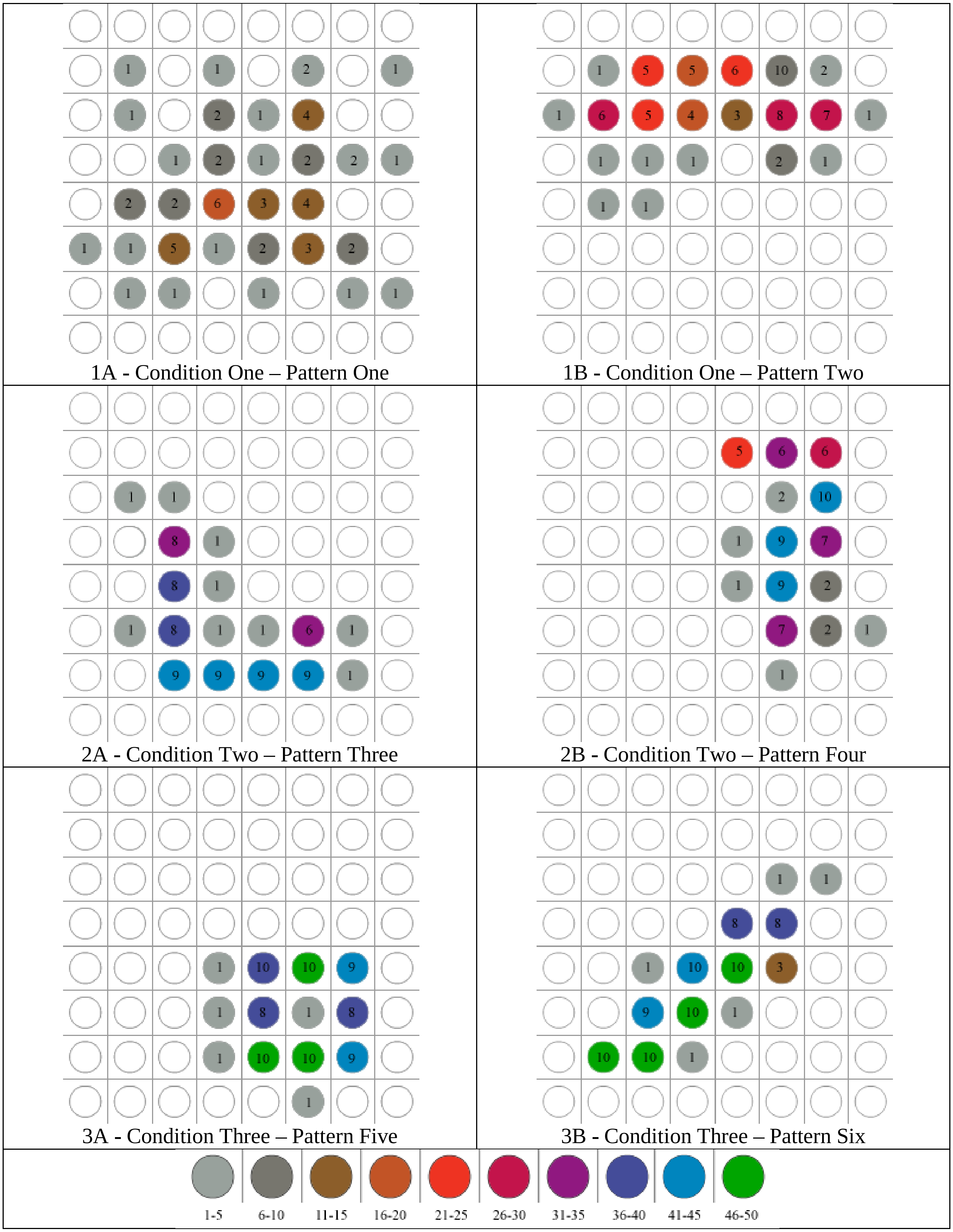


Figure 6.8 Aggregate target pattern confidence ranking related to overall point distributions, which were derived from participants cued sketch scene recreation sheets.



1A - Condition One – Pattern One

1B - Condition One – Pattern Two

2A - Condition Two – Pattern Three

2B - Condition Two – Pattern Four

3A - Condition Three – Pattern Five

3B - Condition Three – Pattern Six

Figure 6.9 Aggregate target point confidence ranking related to overall target point placement tallies, which were derived from participant's cued sketch scene recreation sheets.

6.1.3.2 Participant Observations:

Comments made by participants during and after exploration sessions regarding the usefulness of the Fuse-Map interface were also encouraging. While most users stated that they found their first two exploration sessions to be frustrating and disorienting, most were pleased to find their overall impressions, enjoyment and satisfaction improved as assistance features were added. It is worth noting that users responded differently to the two assistance features even though both generally contributed to better performance. Some users found that the audio coordinate announcements were preferable to the tactile memory aids and vice versa. To explain their preferences most users described themselves as having a particular identified learning style (e.g. "I'm a visual/ kinaesthetic/auditory learner") and associated their assistance preferences with these learning styles. This observation about user individuality corroborates the performative and post-modern perspectives on mapping posited by various critical cartographers (Section 2.7.2). This also suggests that certain modes of map construction or interaction may serve some users better than others. The variability between user preferences and learning styles should be explored as a new direction for research in this field, particularly since truly non-sighted users may have vastly different learning styles than what sighted cartographers may expect.

Many participants reported feelings on initial unease when using the Fuse-Map interface and made comments like "I feel dumb," "This must make me look pretty silly," and "I don't think I can do this." However, positive assurance (e.g. "You're doing fine" or "This is difficult for everyone") from the researcher was well received and helped encourage a renewed exploration effort. Interestingly, participants whose comments suggested that they viewed the demonstration activity as a game or competition, even though no allusions of this sort were made, were seemingly more motivated when exploring new scenes and more diligent when ascertaining pattern configurations. These participants also seemed more satisfied by their exploration sessions afterwards. This observation suggests that framing spatial learning activities in the context of a game or friendly competition, as opposed to a neutral task or assignment, could increase user performance and technology traction. Other researchers have explored the benefits of gaming as a framework for task completion elsewhere and arrived at similar assertions (Walford 1981).

Many participants also linked their performance outcomes to the time of day, personal fatigue and mental preoccupation. Those participants who used the Fuse-Map interface after a long day at work, later in the evening after exercising, or after studying for an exam felt that their performance may have been compromised by their mental fatigue. These comments suggest that map use performed with an interface of this sort may be most successful earlier in the day or before strenuous activities. Similarly, some participants reported feeling a degree of hand strain or posture discomfort when using the interface for a long time, particularly if they preferred an atypical strategy for data exploration. Ergonomic accommodations that allow users to maintain different postures or hand positions should be explored in future versions of this interface to address these concerns.

It is also very likely that each person seeks an individualized sensory balance across the range of stimuli they perceive, such as audio volume, tactile feature prominence and magnetic field strength. Many participants requested that the audio volume be adjusted up or down during their session. Some felt that the coins they used as tactile markers were too easy to move while others wished they could be picked up with less effort. Perceptions of the magnetic attraction of the tactile display also varied among users, with some said it was satisfactory while others wished for stronger sensations. Providing a way for users to adjust interface output intensity will do much to create more pleasing and enjoyable mapping experiences.

Finally, all the users who tried the Fuse-Map interface stated that they could see the potential value of this technology and were inspired to reflect on how vision impairment would affect their own livelihoods. No participant had previously used any form of assistive technology intended for non-sighted people but there was a unanimous sense that the Fuse-Map interface could serve the user’s needs if required. However, further user testing will be required to determine if this perspective remains true for people whose vision impairment is not simulated.

6.1.3.3 Researcher Observations:

External observations made during the first demonstration activity also provided many insights about the Fuse-Map interface’s utility and potential viability. It was noted that there were several factors that seemed to encourage better information synthesis and others that seemed to limit user success.

In some instances glitches or unexpected feedback complicated the use of the Fuse-Map interface. For instance, if a user's hand position changed abruptly or if an errant reflection hit the display field then the IR tracking system would momentarily malfunction. Discontinuous tracing forced the user to remove their tracked finger from the map field and begin their exploration strategy again to re-establish accurate tracking. Since the interface supports bimanual exploration, users were able to mark their location with their untracked hand, remove their tracked hand to reset the sensor and then return to the last point of their search. Nevertheless, malfunctions of this sort (which would be seen as system noise in an information communication paradigm) must be addressed to improve the utility of the system.

The provision of supervised guidance, strategic coaching and exploration tutorials could develop much higher levels of map exploration success for future Fuse-Map users. After observing sixty exploration sessions, certain useful strategies and best practices became apparent, although this information was not shared with participants to avoid skewing results. For instance, most users tended to scan an unfamiliar map scene until they first encountered a target point, at which time they then began a localized search strategy to determine the nature and relationship of adjacent points. However, participants who did not stop searching after finding their first target point and instead continued to explore the entire scene before localizing tended to achieve a more complete awareness of the target pattern. Likewise, participants who completely swept over a target pattern after identifying every point individually tended to have a much better configurational awareness than those who did not complete a final review. Helping users learn and practice these map reading strategies, which can be seen as a form of cartographic literacy, when they begin using a system like the Fuse-Map interface could greatly improve mapping experiences with assistive technologies.

It was also observed that most users experienced a certain amount of drift when attempting to move their finger in a straight path across the map field. In many cases a user did not encounter a point they had expected to because of finger drift (Figure 6.10). Consequently they often assumed that their mental interpretation of the data was incorrect. Providing affordances to minimize finger drift, such as stronger magnetic fields or a straightedge that could be held in the non-dominant hand as a guide could potentially decrease sources of exploration error. Similarly, in many cases the Fuse-Map interface's motion capture apparatus was too precise and users did not bring the tracked point of their finger near enough to trigger a feature's sound cue even though the magnetic field was felt underneath (Figure 6.10). Providing notification when a target feature is nearby could prevent this difficulty. Enlarging the cursor representing the location of the user's finger in the software client could also improve exploration accuracy.

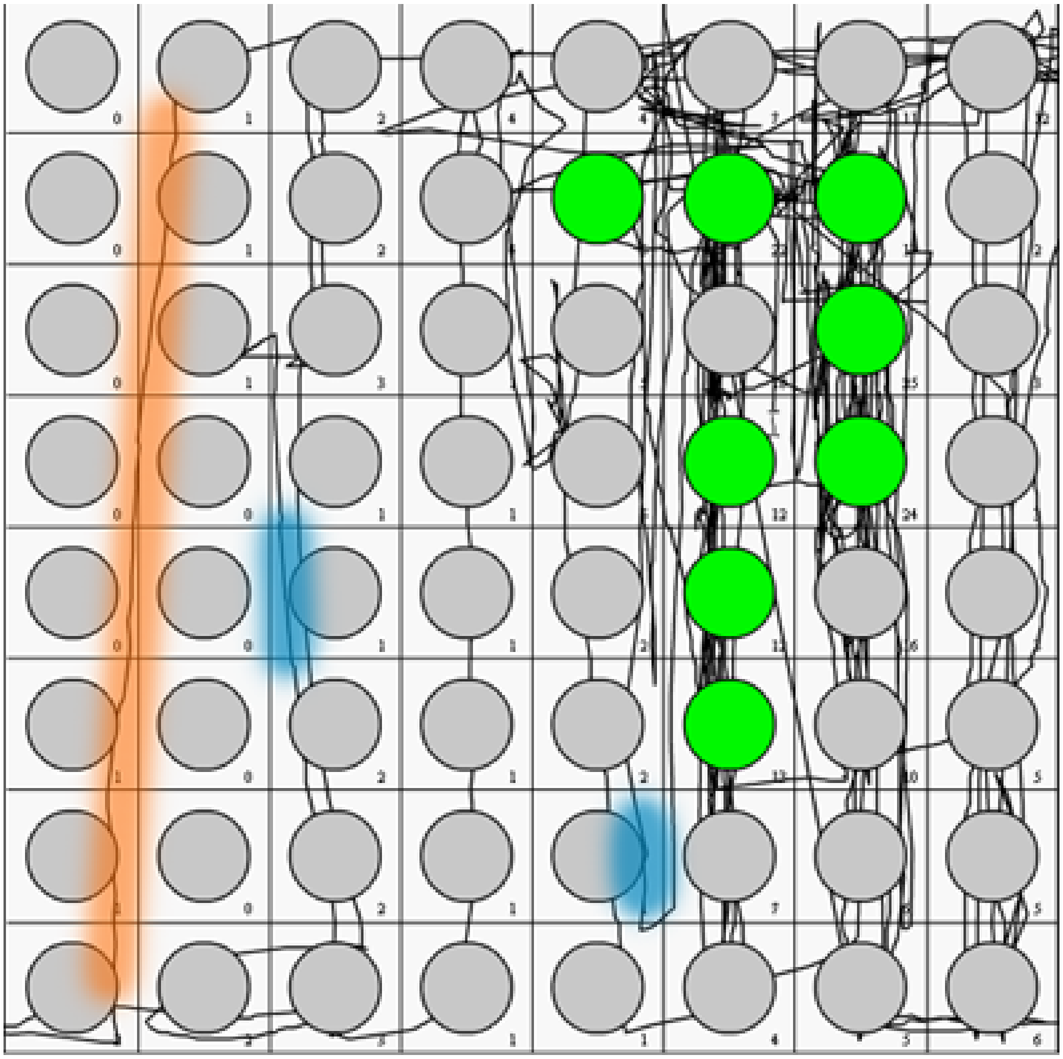


Figure 6.10 Finger drift (shown in red) and near miss instances (shown in blue) are highlighted on a trace snapshot from a participant's exploration session.

Most importantly, the overall impression of observations made by the researcher during this demonstration activity was that of successful map learning. Watching participants use the Fuse-Map interface to explore unknown data scenes did not seem haphazard or unproductive. Even though many users did not recreate certain target patterns with complete accuracy, recorded exploration methods indicated that most were actually finding target features where they intended to look for them. Establishing correct spatial relationships from the identified data proved to be more difficult than expected. Providing additional assistance features and interactive affordances geared towards identifying spatial data relationships should be very beneficial. The provision of contextual information on request, such as the number of target points located within a scene, helped users structure their acquired knowledge in this fashion. Those who received contextual information began to count the target points they had found and/or marked with coins in order to form a more complete mental inventory of the pattern.

The inclusion of subtasks within the exploration procedure, such as “request an audio coordinate for the location of your finger at any point of interest” or “place a coin on all of the points in the target pattern” inadvertently helped encourage users to adopt more methodical exploration strategies with defined milestones and goals. Although no participants used all of the exploration strategies discussed in section 3.4.2, every participant used a select few. Most users also seemed to naturally prefer a small subset of exploration strategies over all others. Teaching the use of non-intuitive exploration strategies and providing recommendations for certain data configurations or exploration phases may be very beneficial (i.e. peripheral exploration when searching for the first target feature, lateral exploration when data is known to be arranged lengthwise across the map, and locally to determine discrete relationships between adjacent features within a compact region.) This observation strengthens the need for a better understanding of non-visual cartography literacy premises.

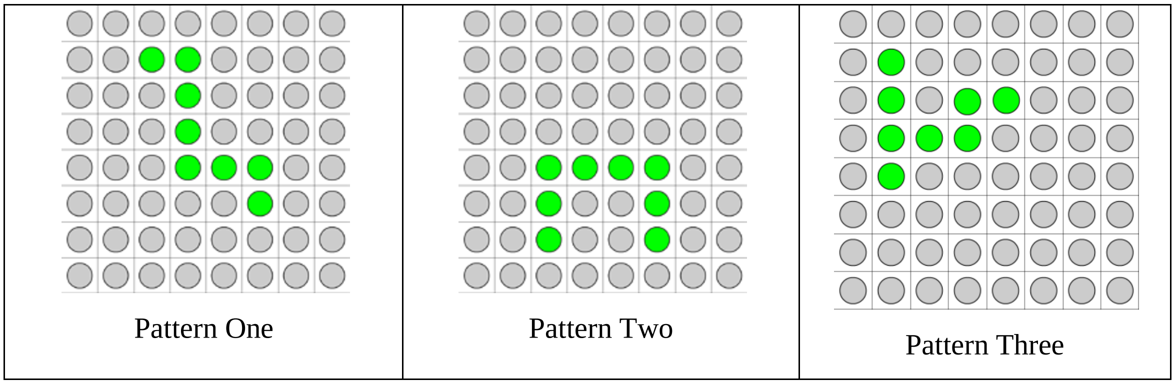
6.2 Demonstration Activity Two – Spatial Data Editing

The second demonstration activity was devised to gauge the Fuse-Map interface's ability to capture user input in ways that support the creation and editing of digital spatial data files. In this activity participants were asked to visually examine a printed eight point target pattern, similar to those in demonstration one, and then recreate the pattern on the Fuse-Map display without the use of their vision. This activity employed the interface's voice recognition and motion capture devices to collect user input within a frame of reference provided by the magnetic tactile display.

6.2.1 Demonstration Procedure:

Three participants who had completed the first demonstration activity also volunteered to complete demonstration activity number two. Due to the unexpected duration of the first activity and the early evident success of the first three participants in demonstration two, a full second round of participant trials was not completed.

The three map scenes used for this procedure were adapted from the Adobe Flash based data representation application used in demonstration one (Figure 6.11). However, the initial state for the second version began with all sixty four feature points of the display set to a neutral state. Voice commands were then used to change the state of a feature point from neutral to target. Participants were taught to activate the feature point at a target location by positioning their IR tracked finger over the desired magnetic pixel and speaking the verbal command "activate". Once activated, a target pixel plated a bell tone when subsequently encountered by the user's finger. Any activated feature point could also then be returned to the neutral state by speaking the command "deactivate" while the IR tracked finger was located over top. Participants of this demonstration activity were not required to rate the confidence of their data creations. Instead, after each editing session the researcher reviewed the data output for errors and captured a screenshot of the target recreation. All recording and observation methods used in demonstration activity one were also used in demonstration activity two.



Pattern One

Pattern Two

Pattern Three

Figure 6.11 Target patterns learned by participants for recreation on the Fuse-Map interface.

6.2.2 Demonstration Results and Discussion

The results of the second demonstration activity very strongly suggested that the Fuse-Map interface could be used to edit digital spatial data files created at a coarse resolution. All three participants were able to completely recreate their known data patterns without error when using the Fuse-Map interface and its audio and tactile assistance features. The only variance between user's data editing activities was the total time required to complete the recreation tasks.

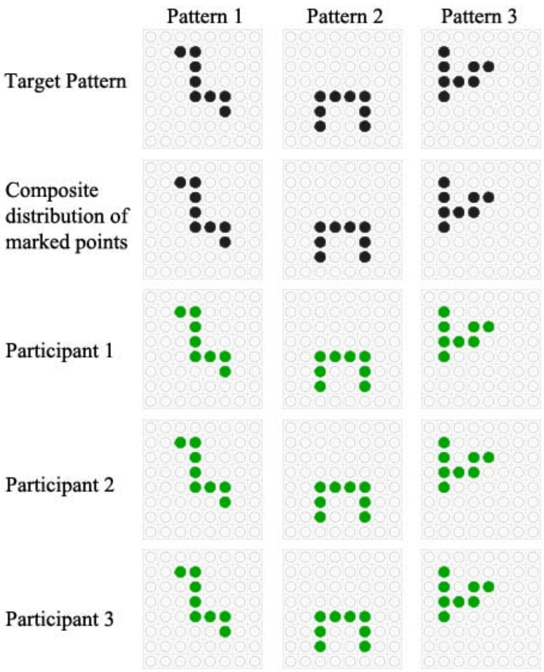


Figure 6.12 Pattern recreation summary for demonstration activity two.

6.2.3 General Observations:

Various general observations can be discussed in addition to the more conspicuous evidence that the Fuse-Map interface can be used to create and output basic spatial data scenes. All three participants commented that they found the data editing tasks tobe easier than the exploration tasks. This difference is likely because the target pattern was learned through a trusted synoptic sensory modality in the second demonstration activity. One participant went so far as to correctly recreate a twelve point target figure in an ad hoc trial of this activity. However, the memory load of recalling more than twelve points began to cause configurational distortions.

The wide variety of scanning strategies that were used to explore the target patterns presented in the first demonstration activity were not used extensively in the second. In almost every instance a lateral or vertical scanning strategy was used to find an initial target point after which a point to point scanning strategy was exclusively used until the pattern recreation was complete. This suggests that there may be very distinct forms of cartographic literacy related specifically to exploring or authoring spatial data scenes without sight.

Observations of participants' behaviours when recreating target patterns on the Fuse-Map interface suggested that two cognitive processes were taking place simultaneously. At one level participants appeared to be processing their mental image of the pattern into a structured configuration. This process sometimes involved sketching the pattern with a finger in mid air or verbally describing the configuration aloud (e.g. “There was a line along the left side.” or “It was shaped like a table”). At another level participants appeared to develop secondary mental models of the target pattern in relation to the map field and the magnetic tactile display before completing the pattern. This process involved individually activating specific target points rather than component portions of the pattern. Making these two activities as congruent as possible, perhaps by enabling users to activate a line of points at once, could help achieve more efficient map authoring sessions.

Future investigation will also be required to determine if the success observed when participants are constructing new data scenes on a blank display can be recreated if new content is added to a display that already shows a certain amount of information. It will be very important to provide a way to differentiate what content was part of the scene's original representation from what a user adds as an annotation.

6.3 Limitations, Concerns and Future Research

The demonstration activities documented in this chapter have shown that the Fuse-Map interface can be used by people without sight to successfully access and edit basic digital spatial data files. The output of these demonstration activities has provided support that the overarching premises of this interface concept are sound. However, a great deal of research remains to truly determine the potential value and limitations of this system's utility, particularly for people who are authentically blind or visually impaired.

Significant limitations related to the two demonstration activity sets must be addressed to qualify the evaluation of the Fuse-Map interface's accessibility, utility and overall viability. The first and most significant issue to be addressed concerns the use of sighted users with simulated vision impairment as demonstration participants. It was intended that these demonstrations should be viewed as a preliminary trial to ascertain how this system could be improved before carrying out future tests with genuinely blind users. However, the true validity of these demonstrations cannot be ascertained until then. It is a common methodological practice in this field to rely on participants with simulated vision impairment, yet the observations discussed in sections 6.1.3 and 6.2.2 are necessarily contingent to some degree upon a lifetime of visual experiences as well as the use of sight at various points in the demonstration procedures. While these observations may be reasonably applied to those lose their vision adventitiously, there may be significant differences for people with congenital vision loss. These differences will likely be most salient with respect to learning styles, preferred sensory balances, and meaningful spatial relationships. Further extensive user testing with genuinely blind participants should, therefore, be carried out to validate the observations made in this in this investigation.

The variety of factors, both human and technical, that seem to mediate the utility of the Fuse-map interface should also be investigated more extensively in future research efforts. While the Fuse-Map interface has shown many indications for the potential value of this technology, a 100% success rate was not achieved during the first demonstration activity. Isolating and testing individual variables in a more controlled fashion will help create a better understanding of this system's operating quality, as long as this sort of empirical testing is used as a means for a larger goal, rather than an end in and of itself.

The fact that only one class of feature was used in the tested depictions of spatial data also limits the evaluation of this HCI. Although certain types of spatial information can be conveyed with a single feature class, most maps and spatial representations rely on discrete distinctions between one or more data types. Knowing that the Fuse-Map interface can process homogeneous forms of spatial data is encouraging, however much more testing will be needed to ascertain if this technology can truly support more complex content.

Finally, the potential for improving the operation of the Fuse-Map interface by integrating other forms of multi-modal technology must also be considered as a necessary path for future research. The inclusion of different output technologies like Senseg’s E-touch technology (Arthur 2012), Tactus’ technology (Ciesla 2012), or vibrotactile haptic technologies commonly used in smart phones could add many unforeseen, beneficial, or even necessary affordances. The entire design approach of the Fuse-map interface may need re-evaluation to implement new additions so this line of research should be pursued before more extensive user testing proceeds.

7 Chapter 7

7.1 Project Review

The central aim of this thesis has been to help advance the state of the art of non-visual cartography by investigating factors that have previously inhibited progress in this field and then exploring new directions for future progress. A broad range of concepts tied to the pursuit of a viable approach for non-visual map access have been unpacked and critically explored in the preceding chapters. In each section, various key findings contributed to an improved understanding of what is required to achieve this goal, however, no individual finding is responsible for enabling new means for serviceable non-visual spatial data access. Nevertheless, when collected and addressed comprehensively these findings provide a solid theoretical foundation upon which new approaches for non-visual mapping can be built.

The investigation competed in this research project was designed to evaluate the validity of three premises that each encompassed new directions for inquiry in the field of non-visual cartography A three tiered approached based on these premises was employed to complete the specific objectives defined for this study. The first tier explored how and why we have experienced difficulty when investigating non-visual cartography and/or devising new mapping strategies to meet the needs of blind and visually impaired people. This involved a critical examination of the ontological assumptions and perspectives at play in this domain of study. It also encompassed an analysis of the strengths and weaknesses exhibited by various accessible mapping technologies and techniques that have been proposed in the past. The second tier developed design guidelines and the operational framework of a new platform for multimodal digital spatial data. This platform builds upon the successes and failures of previous efforts while simultaneously embracing a battery of new user interface technologies and interaction paradigms. The third stage of this study demonstrated and evaluated the viability and effectiveness of the proposed Fuse-Map user interface platform.

The validity of the first premise (Section 1.3.1) addressed in this investigation was supported by the completion of research objective one. A critical review of literature concerning the history, traditional modes of mapping practice and guiding assumptions at play in the field of non-visual cartography explained how mapping tools can be made more useful and accessible for non-sighted people by developing a more comprehensive understanding of non-visual mapping. By deconstructing and unpacking certain taken-for-granted assumptions and research vectors that have characterized the last five decades of studies concerning non-visual cartography many new opportunities, conceptual foundations, ideological concerns, and fundamental priorities for research growth emerged. This new understanding transcends the prior transactional view of mapping as the transfer of knowledge from source to recipient via passive representations.

A new formula, $y = f((a,b,c...)(P_1,P_2,P_{3...}),)$ was derived from this analysis in order to describe a more holistic conceptualization of non-visual map use. This formula is intended to reconstruct the information communication oriented formula, $y = f(a,b,c\ldots)$, devised by Tobin (2008). The new formula asserts that the range of possible achievements of a non-sighted person (y) is a function of the information made available to that person (a, b c) multiplied by the different practices (P_1,P_2,P_3) a map affords that person to facilitate knowledge synthesis activities. Chapter three evaluated the strengths and weaknesses of different methods and technologies that have been used to make spatial data available for non sighted people, while chapter four addressed the different types of affordances needed in order for non-sighted map users to meaningfully process that spatial data. The continued exploration of new strategies for non-visual spatial data portrayal that views mapping as an active and performative process can be seen as an important new direction for non-visual cartographic research.

The validity of the second premise (Section 1.3.2) was supported by the completion of research objective two. The analytical critique of non-visual cartography's historical evolution and current modus operandi has illustrated where and in what contexts non-visual cartographic research has been carried out without sufficient respect for the affordance qualities of maps. The omission of affordance based understandings of mapping was documented throughout the recognized eras of cartographic research up until the emergence of constructivist ideology and the critical cartography movement of the early 2000s.

The findings presented in chapters two, three, and four concerning the theoretical rational, technical methods and functional requirements for improved non-visual spatial data portrayal approaches highlighted specific affordances, secondary interactions and design features that facilitate the synthesis of knowledge from spatial data. The six essential interface design elements discussed in chapter five were derived from these findings. Achieving the most critical of these elements, a data encoding mechanism that leverages multiple sensory modalities and information channels to effectively overlay different layers of spatial information, was the impetus for creating the magnetic tactile data display device described in chapter five. The exploration of new and novel map affordances and secondary interactions that support enhanced multimodal map engagement strategies stands as a second new direction for research in non-visual cartography.

The validity of the third premise explored in this thesis was supported by the completion of research objective three, which was successfully achieved through the construction and demonstration of a working prototype for the Fuse-Map interface. The demonstration activities documented in chapter Six illustrate how novel affordances, such as a magnetic tactile display device, motion capture apparatus and speech recognition software, can make non visual geographic information systems much more accessible to non-sighted people. Observations made of during user trials of the Fuse-Map interface were very encouraging and strongly suggest that this tool represents a very viable opportunity to help make maps and spatial data as accessible to non-sighted people as they are for those with sight.

The first demonstration activity revealed that the provision of secondary interaction techniques for synthesizing spatial data, such as the ability to identify a feature’s location coordinates or place tactile memory aids, helped map users internalize new spatial data scenes with high levels of accuracy, completeness and certainty. The second demonstration activity revealed that an effective interface design framework will allow non-sighted map users to accurately create new non-visual representations of familiar basic spatial data arrangements with little difficulty. The continued development and refinement of non-visual geographic information systems based on the ne w Fuse-Map design framework stands as another new direction for future research in the field of non-visual cartography. Furthermore, a greater emphasis on the significance of non-visual cartographic literacy as well as user specific map exploration behaviors, symbology preferences, and learning styles should also be established.

7.2 Future work

The investigation and analysis discussed in this thesis represent only the first steps along a newly unfolding trajectory for research concerning accessible multi-modal spatial data systems. The findings and innovations presented here represent only a basic foundation upon which more complex and comprehensive investigations can be built.

The need to rely upon individuals with simulated blindness participating in laboratory bound demonstration activities is perhaps the largest limitation of this research project. To overcome this limitation and prove the value of the Fuse-map prototype concept, a more thorough experimental program will be required. Further research in this vein should attempt to explore the practical value of this technology for truly non-sighted people, particularly those who have little to no previous visual experience.

The data rendering density and clarity that can be achieved with a magnetic tactile interface will be the biggest determinant of this technology's viability. At present only very coarse spatial images can be achieved, and yet most spatial data types require very elaborate representational elements. Various modern technologies that have been developed for use with advanced human computer interfaces could potentially be used to augment the Fuse-map display system and improve either data richness or resolution. Senseg Inc's Tixel technology (Arthur 2012), 3d-spatialized audio, and stereo camera based motion capture computer-vision technology are three examples of innovations that could be integrated into the Fuse-map design platform to provide highly refined input and output functionality.

The full value of technologies like the Fuse-Map interface cannot be realized if they are not given a vehicle to reach the intended end users. Many technologies that have previously been developed in academic settings for blind and visually impaired users have been foundered by insufficient infrastructure and product development support. Determining what steps will be required to commercialize technologies such as this is an important consideration that will define how well a platform like the Fuse-Map interface gains traction with its intended end user.

7.3 Closing Comments

The pursuit of means to provide blind and visually impaired people with complete and serviceable access to maps and spatially portrayed data is an ambitious goal. The magnitude of resources and dedication that will be required to complete this project cannot be understated and only the first very small steps forward have yet been taken. Nevertheless, there can be no doubt that there is much to be gained in the pursuit of this goal. By exploring new ways for people without sight to participate in geographic discourse, those who have not lost their vision may also begin to see geography and the world around them in a new way. The phenomena of the geographic world are sensuous, rich, and engaging, and there is far too much to be lost if we can only distil our environmental perceptions into simple pictures on a sheet of paper.

In the next era to come it is likely that we will see a democratization of cartography. The field as we know it will no longer be led by specialists who hold exclusive authority to define what mapping is and how it works. Instead, new technologies and ways to create and disseminate maps and spatial data will enable the vast populous of map users to push cartography in new directions according to their needs and identities. For non-sighted people the democratization of cartography will hopefully represent a critical opportunity that defines new and more integrated roles for this community in cartographic congress. It will represent a shift for non-sighted people from an often overlooked market audience for map products to active participants in mapping research and authors of new content that describes a unique and previously unshared geographic umwelt. If maps are to be stories about the world told through symbols and shapes, we must rally together to help them to include everyone’s stories for all our greater good.

8 Glossary of Terms

Term	Definition
3D Printing	A method for creating textured tactile relief maps using a specialized computer printer to build up deposits of a sculpting material, such as resin or epoxy, in order to create a three dimensional physical object.
Adventitious Vision Loss	Vision loss that is caused by an accident or degenerative medical condition later in life after birth.
Allocentric Information	Geographic information that is referenced to an environment as a whole or multiple independent features within a landscape, rather than from an individual's personal perspective. (e.g. Calgary is south of Edmonton and east of the Rocky Mountains.)
Avatar	A symbolic icon or movable object that can be used to represent a person in an interactive computer program.
Bimanual Interaction	The use of two hands to explore or manipulate an object.
Cartographic Milieu	The ontological environment or social setting created by various schools of cartographic thought at any given time.
Cartographicacy (Cartographic Literacy)	Learned skills for reading, interpreting and understanding maps and geographic information, or the ability to read, interpret and understand maps using a set of mapping skills.
Casting	A method of creating textured tactile relief maps by allowing a fluid casting material, such as plater or epoxy, to harden in a mold.
Congenital Vision Loss	Vision loss that occurs prior to or at the time of birth.
Craft Production	A method of creating textured tactile relief maps by building a physical representation using various crafting materials, such as wood, paper, cardboard, beads, sticks, cloth, and glue.
Crowd Sourced Content	A method of developing map content by outsourcing data collection tasks to a community of public users who submit their findings, typically via the internet, to a central publisher or collaborative software platform.
Cutaneous Sensation	The collection of stimuli through the nerves of the skin.
Earcons	A portmanteau of ear and icon. Symbolic or iconic sound clips that are used to tag and identify specific features in an interactive sound map.

Effector	A computer peripheral device or object that senses and communicates a user's movements and commands to a computer and/or provides sensory feedback to the user. (e.g. A computer mouse is an effector)
Egocentric Information	Geographic information that is referenced to an individual's personal location or self aware point of view. (e.g. You are facing the bus stop and main street is on your left side.)
Embossing	A method for creating textured tactile relief maps by imprinting shapes and patterns into a malleable material, such as metal, paper or plastic, using pressure and hard templates.
Etching	A method for creating textured tactile relief maps by engraving or carving material out of a surface in order to imprint a specific shape or pattern.
Geographic Information System	A computer based mapping system that can collect, display, edit, store, and analyze geographic data.
Georeferenced	To establish the location of an object within physical space by defining a set of known coordinates using a structured reference system.
Geovisualization	Tools and cartographic analysis techniques that produce new data and geographic information sets in the form of visual imagery.
GIScience	Geographic Information Science is the academic discipline concerned with the development, use and application of geographic information systems and spatial analysis.
Haptic	Phenomena related to the sense of touch, tactile perception, and physical actions, particularly with respect to computer input and output.
Haptic Soundscapes	A digital environment, representation, or computer interface regime that engages users through the sense of touch and hearing simultaneously.
Interactionally Rich Systems Analysis	A form of design analysis concerned with utility and functionaty, such as how an instrument or tool may be used by a person to complete an action upon an object.
Invarients	The salient features and properties of a map that represent unique phenomena and remain unchanged between a user's observations.
Kinesthetic Perception	An awareness of the body’s movement and motion.
Location Aware Devices	Computer equipment and electronic devices that are able to determine their physical location using GPS signals or from other spatial attributes such as IP Addresses, wireless connections or telephone numbers.

Map Mashups	Combining two or more distinct sources of map content or mapping techniques to create an entirely new geographic representation that presents novel information, relationships, or cartographic perspectives.
Modality	
MultiModal	Having or employing many different modes or types of phenomena in parallel. (e.g. A computer system that presents information using sound, vibration and a visual display is multimodal.)
Multi-Touch	Computer hardware or software that can identify and track two or more points of contact from a user so that complex gestures can be used to operate an interface.
Non-sighted people	Individuals who are partially visually impaired or who have no sight.
Ontogenic	Related to the generation and derivation of new knowledge, concepts, and ideas.
Post-modernism	The post-modern school of thought rejects the need for objective truth and instead allows for diverse, context dependant interpretations of the world.
ppGIS	Public Participation GIS
Proprioceptive Sensation	An awareness of the body's position and posture.
Reality Based Interactions	Computer interactions that mimic a user's familiar ways of interacting with the surrounding environment, such as turning a page, talking to another person, lifting and moving an object, or filing a document in a folder.
Remote Sensing	The process of collecting information about the Earth’s surface by capturing reflected light or energy using a distant sensor, such as a satellite or aircraft mounted camera.
Sensory Aperture	The physical extent within which a sense organ can collect stimuli from the outside world (e.g. Field of view, hearing range, or exposed skin area.)
Sensuous Geographies	Interpretations of geography and the physical world that are concerned with unique sensory perceptions and environmental attributes, such as aural or olfactory landscape characteristics.
Serial Perception	A form of perception wherein individual stimuli from the surrounding environment are encountered and processed individually one after another.
Spatial memory	An individual;s mental recollection about the layout of a landscape or arrangement of features within a general spatial frame of reference.
Stylesheets	A set of rules that define layout and appearance a structured digital

	document.
Surface Tactile Phenomenon	Surficial attributes of an object that can be detected through the sense of touch and the nerves of the skin.
Survey Knowledge	Overall knowledge about the distribution and layout of a landscape and all the features found within its boundaries.
Symbology	The use of symbols to represent data and specifica pieces of information.
Synchresis	The simultaneous and synchronized occurrence of two or more sensory stimuli.
Synoptic Perception	A form of perception wherein many different discrete stimuli from the surrounding environment are all identified and processed together at once.
Umwelts	The world as it is uniquely experienced by a particular person or organism, according to their sensory capabilities and cognitive processes.
Unimanual Interaction	The use of one single hand to explore or manipulate an object.
Universal Design	A philosophy that emphasizes barrier free, inclusive design that allows all people to use an item or space regardless of individual differences.
Vacuum Forming	A method for creating textured tactile relief maps that uses negative pressure or a vacuum to press a maliable material, such as metal, paper or plastic, into the shape of a hard mold.
XML	Extensible Markup Language. A computer programming language that allows information to be encoded as a particular type of element within a document's hierarchical information structure.

9 Appendix A – Materials from Demonstration Activity One

9.1 Demonstration Activity Protocol

1. Pre-Activity Preparation
    a. Assign participant code to next participant
    b. Load and prepare demonstration flash scenes and recording equipment
    c. Retrieve demonstration documents from activity binder (Overview sheet, Ethics agreement, blank cued sketch sheets)

2. Introduction
    a. Welcome participant to Immerse Lab
    b. Provide activity overview documents and verbal explanation
    c. Discuss activity objectives and tasks
    d. Answer any participant questions
    e. Complete and file ethics form

3. Training
    a. Seat Participant at blank display
    b. Load training scene and explain training activity
    c. Ask participant to put on finger piece and blindfold
    d. Complete training activity
    e. Confirm that user recognizes distinct sounds and cues
    f. Answer any participant questions

4. Demonstration Activity
    a. First condition tasks
        i. Load flash scene for first condition tasks and begin recording
        ii. Explain first condition exploration task to participant
        iii. Allow participant to complete exploration task for condition one, scene one
        iv. When task is complete ask participant to rotate chair to second table and remove blindfold
        v. Explain first condition recall task to participant
        vi. Allow participant to complete recall task for condition one, scene one
        vii. When task is complete ask participant to put on blindfold and rotate chair to first table
        viii. Repeat task explanation if necessary
        ix. Allow participant to complete exploration task for condition one, scene two
        x. When task is complete ask participant to rotate chair to second table and remove blindfold
        xi. Explain recall task to participant once more if necessary
        xii. Allow participant to complete recall task for condition one, scene two

    b. Second condition tasks

   i. Load flash scene for first condition tasks and begin recording
   ii. Explain first condition exploration task to participant
   iii. Practice assistive protocol (Location request or tactile marker)
   iv. Allow participant to complete exploration task for condition two, scene one
   v. When task is complete ask participant to rotate chair to second table and remove blindfold
   vi. Explain first condition recall task to participant
   vii. Allow participant to complete recall task for condition two, scene one
   viii. When task is complete ask participant to put on blindfold and rotate chair to first table
   ix. Repeat exploration task explanation if necessary
   x. Allow participant to complete exploration task for condition two, scene two
   xi. When task is complete ask participant to rotate chair to second table and remove blindfold
   xii. Explain recall task to participant once more if necessary
   xiii. Allow participant to complete recall task for condition two, scene two

c. Third condition task
   i. Load flash scene for first condition tasks and begin recording
   ii. Explain first condition exploration task to participant
   iii. Allow participant to complete exploration task for condition three, scene one
   iv. When task is complete ask participant to rotate chair to second table and remove blindfold
   v. Explain first condition recall task to participant
   vi. Allow participant to complete recall task for condition three, scene one
   vii. When task is complete ask participant to put on blindfold and rotate chair to first table
   viii. Repeat exploration task explanation if necessary
   ix. Allow participant to complete exploration task for condition three, scene two
   x. When task is complete ask participant to rotate chair to second table and remove blindfold
   xi. Explain recall task to participant once more if necessary
   xii. Allow participant to complete recall task for condition three, scene two

d. Debrief
   i. Allow participant to compare cued recall sheet with graphical trace image
   ii. Explain to participant how demonstration observations will be utilized
   iii. Answer any remaining questions
   iv. Save and store recordings of participants demonstrations

10 Appendix B - Digital Appendices

Demonstration Activity Trace Images

Fuse-Map Interface Engineering Design Report

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