EXPLORING NEW DIRECTIONS IN NON-VISUAL CARTOGRAPHY: AN OVERVIEW OF THE FUNCTIONALLY SEPARATED MULTI-MODAL MAP RENDERING SYSTEM

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Abstract:

The highly pictorial nature of contemporary maps and geographic reference sources creates an accessibility barrier for the blind and visually impaired. Without access to spatial information, the capacity for independent mobility, spatial perception, and geographic communication may be significantly reduced for those who cannot utilize traditional visual maps. At the root of this barrier are limited tactile map publishing technologies, inadequate human/computer interfaces, and tactile content formatting conventions that are ill suited for enabling non-visual access to complex spatial data. The need to transpose visual cartographic content into a format that is perceptible using alternate senses has inspired a wide range of approaches for non-visual cartography, however none have yet achieved more than limited success.

This paper describes an investigation assessing the functionality and viability of a novel multi-modal audio-haptic computer interface intended for non-visual geographic information retrieval. This system, referred to as the Functionally Separated Multi-Modal Map Rendering System [Fuse-Map], represents a potential advancement for non-visual cartography and human computer interface design. It consists of an infrared hand tracking apparatus; an electromagnetic dynamic tactile 'display'; speech recognition, synthesized speech, and non-speech audio; and static tactile spatial reference features. Infrared finger tracking effectively enables users to explore virtual map content while retaining somatic sensations, such as the ability to feel a tactile reference markings or magnetic textures embedded within the desktop surface. This feature allows an unprecedented ability to superimpose cartographic content without incurring significant sensory confusion. Refreshable magnetic display technology does allow for dynamic object identification and bimanual exploration of spatial variation at a coarse level, but low content density and resolution capacities remain a significant issue to be resolved. Voice recognition features appear very well suited for use in this context and do much to reduce user confusion and frustration in comparison with traditional mouse and keyboard systems, however the voice training required to create a functioning user profile is not easily accomplished with visual impairment. The amount of information that can be accessed using verbal queries is

far larger than what can be provided through Braille labeling on a traditional tactile map.

Interface functionality was tested by ten volunteer participants, with simulated vision impairment, who were asked to identify a number of varied eight point patterns within a six by six grid of points presented using the Fuse-Map system. The participants' ability to correctly identify these patterns in three different interaction conditions was observed in order to demonstrate and analyze the capacity for geographic information retrieval provided by this interface. A variety of data collection methods, including the completion of post exploration model recreation tasks, cued sketch completion, video recordings, talk-aloud protocols, and direct observation were used to gather data regarding the interface's usability and functionality.

While user testing of the Fuse-map system remains ongoing, initial proof-of-principle trials in a laboratory setting indicate a high potential viability for this platform as a means to enhance universal access to geographic products. The results of this study indicate that at a coarse data level, the Fuse-Map system meets and in some ways surpasses traditional raised line paper and virtual reality/force feedback tactile mapping methods. An additional benefit to the magnetic tactile display used in this system, which cannot be found in other tactile interfaces, is the ability to place metallic markers on the display surface without obscuring the magnetic features themselves. This provides a form of tactile annotation, akin to highlighting or circling points of interest in ink on a visual map, and allows users to easily track and return to previously explored portions of the map.

Introduction:

One of the many difficulties experienced by those with vision impairment emerges from the communication barriers that prevent non-visual access to highly pictorial cartographic products and geographic reference sources. Without access to spatial information, the capacity for independent mobility, geographic learning, and communication concerning spatial concepts may be significantly reduced for anyone who cannot utilize traditional visual maps (Luxton and Banai, 1994; Gollege, 2004). Furthermore, Pow (2007; pp.1) asserts 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". As such, the primary purpose of this research is to develop, test, and refine means for non-visual geographic information retrieval using an appropriately designed computer interface. While the need to transpose visual cartographic content into a format that is perceptible using alternate senses has inspired a wide range of approaches for non-visual cartography, none have yet achieved more than limited success. As such, this investigation is intended to address the call for further research and innovation posed by Vidal Verdu and Hafez (2007, pp.1), among others (Power, 2008; Rassmus-Growhn,2006; Lahav & Mioduser, 2002), who posit in their thorough survey of tactile interface technologies that "the goal of an efficient low-cost tactile display for visually-impaired people has not yet been reached".

This paper outlines and evaluates the design parameters and functionality of a prototype audio-haptic computer interface intended to establish non-visual multi-modal access to maps and geographic reference sources. Recent advances in human computer interaction technology offer a new direction for the next generation of non-visual interface platforms. Innovations in multi-touch, motion capture, voice recognition and speech synthesis technologies, as well as natural user interface operating systems offer avenues for intuitive human computer interactions that allow users to manipulate and explore information in a highly immersive and acutely kinesthetic manner. By leveraging these technologies, the interface introduced in this investigation is able to offer persons without sight a more meaningful synergy of sensory perceptions and control activities through functional multi-modal separation. This system, referred to as the Functionally Separated Multi-Modal Map rendering system [Fuse-Map] represents a largely unprecedented approach for universal accessibility in geography that provides rich sensory immersion and intuitive interactivity.

Approach:

The general inspiration for this project can be attributed to the activities of various individuals in the North American community of "body-modification" enthusiasts. Shannon Larratt, Jesse Jarrell, Todd Huffmann, and Steve Hawarth, among others, have provided reports about experiments with different techniques for implanting rare earth magnets under the skin of a fingertip (Jarrell, 2006). From their experiences, these individuals assert that, after a temporary healing and adaptation period,

magnetic implants can provide a capacity for the perception and sensation of electromagnetic fields without interfering with cutaneous tactile sensation. While it was concluded that the implantation of magnets is not a viable procedure, the premise that electromagnetic fields may be utilized as a novel channel for tactile perception remains valuable. Instead of placing magnets beneath the skin, it is certainly possible to affix a magnet or ferrous probe to the outer surface of one's finger, without any health risk, in order to explore the attractive and repelling interactions of magnetic fields in the same way that a blind individual would explore the dots and textures that make up Braille text or a tactile map. In this manner, by activating sets of adjacent electromagnets in predefined patterns it is possible to encode spatial data in a very coarse fashion.

A critical issue that has impaired previous attempts to enable non-visual geographic information retrieval via haptic interfaces is the tendency for confusion that occurs when all direct actions and feedback stimuli involved in exploring and manipulating an unseen map are channeled entirely through a user's hands, fingertips, and ears. Confusion may be compounded by the need to hold or grasp a mouse or haptic peripheral (Schneider & Strothotte, 2000), often in only one hand, when using a personal computer. This simultaneously monopolizes somatic sensations, enforces unimanual exploration, and obscures the spatial frame of reference of the map.

A central premise at the core of this research is that blind users will be better able to interact with electronic maps if the interface's control functions are separated to particular channels, such as voice commands, thereby leaving the users aural, tactile, and proprioceptive senses, among others, undistracted for exploration. Several studies have found that the augmentation of haptic and tactile interaction models with audio feedback provides an enhance learning environment for non-visual users (Duanys & Laruska, 2007; Alonso, 2006; Rassmus-Grohn, 2006; Braun, 2006; Jeong & Gluck, 2003) The concept of functional separation, as it is used in this study builds upon the discussions of Cognitive Load and Dual Coding theory provided by Jeong and Gluck (2003, pp.230) in their analysis of multi-modal audio-haptic GIS systems. These theories suggest, respectively, that people possess a limited working memory and information processing capacity, and that overall processing effectiveness is increased when the cognitive load placed on individual perception centers within the brain is decreased. As such, a person's effective information/stimulus processing capacity can be increased by encoding and distributing information across multiple sensory modalities, each of which has its own working memory. Multi-modal separation of data input and output functions thereby minimize the amount of cognitive load that is placed upon each of a user's perception centers and thus increases processing capacity. It is expected that this increase will lead to better uptake of presented cartographic information as well as less user frustration when using the Fuse-Map interface.

An analogous 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 also simultaneously listening for traffic updates or directions from a radio, gps device, or passenger. Additionally, the driver receives feedback through alternate sensory modalities when driving the car, by feeling the position of the wheel and accelerator, experiencing sensations of movement or vibration, or watching visual cues through the window when turning or accelerating. It is the separation of actions and perceptions combined with the provision of meaningful sensory feedback that allows the driver to intuitively and successfully operate a vehicle with little confusion. However, if the car was designed so that each control could only be operated by the driver's dominant hand with close visual attention, and little or no feedback was provided to tell the driver how far the car was turning with each movement of the steering wheel, the necessary balance of functional synergy would be lost. In demanding situations the driver would likely lose control of the car or lose track of the road very quickly. The greatest clarity of understanding, in regards to the perception and cognition of the sensory stimuli, is thus achieved through meaningful constructions of stimulus events. At all times, information must be mentally inferred from sensory feedback provided in response to user input activities. As such, when developing a non-visual method for geographic learning, if richer and more meaningful sensory feedback can be obtained from a system that enables intrinsically spatial tactile user interactions, then better mental inferences can be made regarding the content of an unseen map.

Unfortunately, non-visual map exploration is a mentally demanding activity and there has not yet been an accessible map rendering interface developed that has achieved such a successfully synergistic design. In instances where a blind user is exploring a map on a conventional personal computer, a standard mouse or pointing device (touch screen, drawing tablet, force feedback mouse, haptic mouse, etc) and keyboard are the devices most often used to both explore and manipulate the map scene. If a user is exploring a scene using the mouse pointer and wishes to type a keyboard command, to scroll or zoom in on the map for instance, both the user's attention and hand must be transferred from the mouse to the keyboard. At this point the established proprioceptive frame of reference as well as the attention the user had devoted to the exploring the scene becomes lost or confused. This study seeks to determine if functional separation can assist visually impaired map users by utilizing voice commands rather than keyboard input, finger tracking rather than mouse input, along with magnetic landmarks and audio cues to provide meaningful feedback.

To achieve the intended goal of computer based multi-modal map rendering, the Fuse-Map system presented herein utilizes infrared motion capture technology, rather than traditional mechanical devices, to track the position and movement of one or more fingers across a desktop surface. Software protocols developed by Human Computer Interactions expert Johnny Chung Lee allows a Nintendo Wii remote control to be used as an motion tracking device for points of infrared light (Chung Lee, 2009) [A]. This allows the registration of fingertip locations, identified by infrared light emitted from an IR LED attached to the finger [I], as coordinate points for mouse cursor positioning. Although touch sensitive surfaces have been used in other research projects in this field (Blenkhorn and Evans, 1998) the innovation provided by Lee

uniquely allow tactile representations to be placed below a user's fingers by enabling tracking from above. A user with a magnetic probe on one or more fingers [J] can then explore tactile patterns created by a dot-matrix style 'display' of electromagnets embedded in the desktop surface [D], while simultaneously interacting with the virtual scene [E] using one finger to move a digital cursor. Voice recognition technology [F] allows the user to issue commands that query or manipulate the virtual map scene without changing hand positions, thereby maintaining spatial coordination. Additional sensory feedback from the system is issued audibly via recorded earcons (audible icons or sound clips) and speech synthesis [F]. A digital projector [B] and video camera [K] mounted overhead and aimed at the desktop surface allows the research to calibrate test scenes and record participant trials. The function of these components is coordinated by a single personal computer [C] and together they provide an interaction platform that is highly intuitive, synoptic, and flexible.
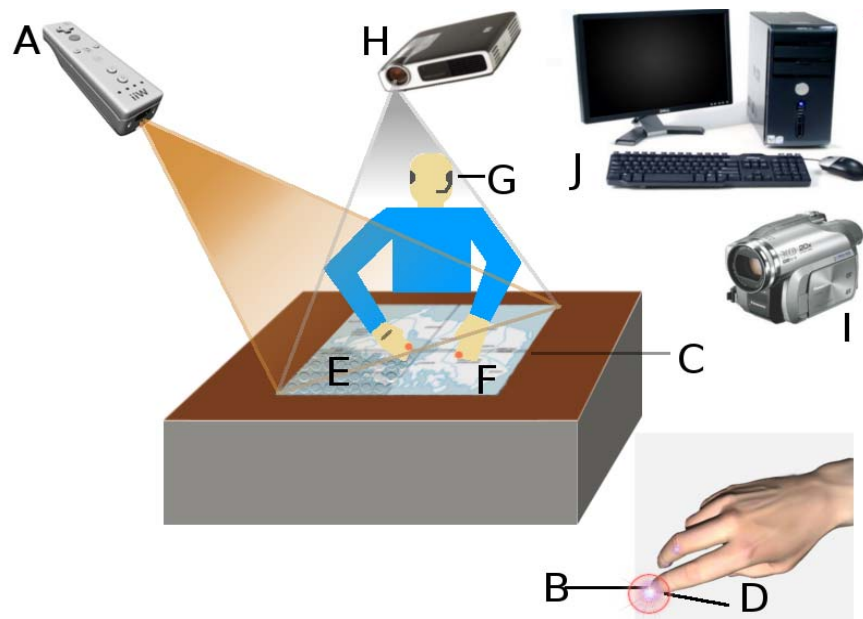

Figure 1: Illustration of the Fuse-Map interface's components and design

In "Multimodal Virtual Reality Versus Printed Medium in Visualization for Blind People," Yu and Brewster (2002, pp. 58) compare the strengths and characteristics of typical multimodal virtual reality computer interfaces against traditional raised line tactile maps. Adapting the summary table produced in this analysis to include a comparison of the Fuse-Map system [See Table 1] highlights the relative strengths of this system and the advancements and/or limitations it holds when compared to traditional approaches.

When assessing the investments required to create both tactile and virtual reality map products, Yu and Brewster note that initial hardware expenses are generally much lower for tactile diagrams than for virtual reality systems. However, the end product production cost and publishing time for VR maps is much lower since no physical materials need to be purchased after the system is acquired. Additionally, virtually rendered maps can be altered quickly by simply editing the parameters of the digital map document being presented, without labour intensive Braille translation or tactile design work (Clark & Clark, 1994; Graf, 2008). In comparison, the Fuse-map system has much lower hardware investment costs than a high end virtual reality system, but retains the same rapid production speed and modification ease as a typical VR system. The laboratory prototype of the Fuse-map system used in this study was completed for less than $1000 CAN and included a Nintendo Wii remote, infrared tracking supplies, a digital projector, a desktop stand and hardware, a wireless audio/microphone headset, and a rudimentary electromagnetic tactile display. It is important to note that

Category	*Tactile Diagrams*	*Virtual Reality Systems*	**Fuse-map interface**
Cost	*Low*	*Varies*	Low
Production Time	*Long*	*Short*	Short
Easy to Change	*No*	*Yes*	Yes
Durability	*Low*	*High*	High
Familiarity	*High*	*Low*	Medium
Dimension	*Two*	*Three or more*	Two
Modality	*Single*	*Multiple*	Multiple
Bandwidth	*High*	*Low*	High

Table 1: Characteristic Assessment of Tactile Diagrams, Virtual Reality Systems and the Fuse-Map Interface (Adapted from Yu and Brewster, 2002 - all italics excerpted directly)

the production a more advanced electromagnetic tactile display may significantly increase costs. Yu and Brewster (2002, pp. 58) place the price point of an upper end

consumer VR device, the SensAble Phantom OMNI, at over $10,000.

The ability to alter the composition and content of a map scene by activating or deactivating selected electromagnets, and/or altering *Earcons* and speech synthesis labels, makes the Fuse-map system a highly dynamic rendering platform (Braun, 2006). The use of raised line boundary features and physical markers to provide spatial reference cues, in tandem with the audio-haptic sensory data provided by speech/earcon output and the magnetic tactile display, synergistically engages the user's senses and provides a truly multi-modal interface characterized by a moderate level of stimulus familiarity. The desirable capacity for bimanual scene exploration (Lindeman, 1999; Ballesteros et al., 1997) provides the Fuse-Map interface with a high level of stimulus bandwidth. Unfortunately, the design of the Fuse-map system does limit cartographic rendering to two dimensions as the users hands must remain flat on the desk surface in order to perceive the system's magnetic and raised line tactile features. Finally, the physical design of the Fuse-map system provides a high degree of durability, unlike tactile diagrams, though it cannot yet match the portability of a paper based map.

An additional benefit to the magnetic tactile display used in this system, which cannot be found in other tactile interfaces, is the ability to place metallic markers on the display surface without obscuring the magnetic features themselves. This provides a form of user annotation, akin to highlighting, or circling points of interest in ink on a visual map, and allows users to easily track and return to previously explored portions of the map. Participants emphasized that this features, in and of itself, provided a tremendous boost to their confidence and scene understanding.

Evaluation Procedure:

To explore the performance parameters of the Fuse-Map system and obtain a body of observational data from which to propose and refine useful non-visual cartographic conventions and GIS software functionality, ten participants were invited to explore experimental test scenes that depicted variations of an eight point pattern within a six by six grid of points, each of which was superimposed upon a magnet located just below the desktop surface. [See Figure 1] Although the test scene design used in this experiment involves high simplified cartographic representations, there is nevertheless a very short conceptual distance between eight point patterns and representations of more sophisticated point based data maps, such as subway and transit maps.

Figure 1: A participant with simulated vision impairment explores a test scene using the Fuse-Map Prototype. Target points are shown in blue.

Three experimental conditions were tested by each user, with two scenes explored for each condition. The first condition required the participant to explore and identify the eight target points without any assistance. The second scene again required the participant to explore and identify the eight marked points, however when a verbal command was spoken, a text to speech synthesizer would provide the grid location of the exploration finger. In the third condition, participants were once more required to explore and identify the eight marked points in both test scenes, with the ability to query the grid location of their exploration finger, but were also asked to place magnetic markers (small coins) on the eight target points. After exploration of the third condition test scenes was completed, the positions of the magnetic markers were recorded and cleared before the participants' blindfolds were removed to complete the cued sketch. This procedure allowed for a comparison of a user's ability to find the eight target points against their cognitive internalization of the points' positions within the grid.

After exploring each test scene, participants were invited to complete a cued sketch (Kitchen & Jacobson, 1997) by shading points on a six by six grid of circles in order to recreate the identified pattern on paper. In addition to shading in circles to depict the test scene pattern, participants were also asked to rate their confidence of the correctness of their sketches by writing a number between one and five on each of the marked points in the sketch, with one indicating no confidence and five indicating complete confidence. Tracking confidence levels allowed for a correlation to be tested between querying or marking techniques and the spatial cognition of target points.

Results:

These experiments evaluated the functionality of the Fuse-map system in terms of the participants' demonstrated ability to uptake and internalize presented information. The findings of this battery of tests performed with the Fuse-map system were both instructive and clear. While participants were able to demonstrate a better than chance ability to identify the patterns when exploring in the first condition (no exploration aids), significant distortions occurred and participants' confidence in their own recreation sketches was very low.

An average of four, out of eight, target points were correctly identified in condition one tests and a mode confidence score of two out of five was obtained. However, when exploring scenes in the second test condition (location query available) a significant decrease in pattern distortions and a corresponding increase in confidence occurred. Of the ten participants, six were able to create complete recreations of the target pattern, wherein all active points were identified and placed in their correct locations. The remaining four participants who did not achieve completely accurate recreations had only minimal distortions in their cued sketches.

Participant exploration of the two condition three test scenes (location query and 'annotation') achieved a very high rate of learning. All ten participants were able to successfully recreate at least one out of two test scenes, with seven participants out of ten completing both correctly. A mode confidence score of five out of five was obtained for condition three tests. Additionally, the remaining three scenes that were not successfully achieved had only a single distortion, which was a point misplaced within one unit of the correct position. There is a reasonable likelihood that the distortions observed in the nearly correct condition three cued sketches may have been a result of operating errors experienced by the Fuse-Map system. This is suspected because all magnetic markers used in the position three tests were positioned correctly, despite the subsequent recreation errors.

Discussion:

Numerous salient findings can be derived from initial observations made of the Fuse-Map system's performance in participant trials. It has been observed that the magnetic tactile display and infrared hand tracking apparatus offer powerful new ways to explore map content in an intrinsically spatial manner. Additionally, users have little difficulty learning and utilizing voice commands for hands free GIS exploration and manipulation. The combination of immersive tactile representations with interactive audio feedback is a particularly effective method for conveying basic spatial information. Infrared finger tracking effectively enables users to explore virtual map content while retaining somatic sensations, such as the ability to feel a raised line boundary around the display area or magnetic textures embedded within the desktop surface. This feature allows an unprecedented ability to superimpose cartographic content without incurring significant sensory confusion or undesirable design clutter

(Amick & Cocoran, 2004; Challis, 2000; Eriksson, 1999). Additionally, the amount of feature attribute information that can be accessed using verbal queries is far larger than what can be provided through Braille labeling on a traditional tactile map.

Refreshable magnetic display technology does allow for dynamic object identification and bimanual exploration of spatial variation at a coarse level, but low content density and resolution capacities remain a significant issue to be resolved. Issues of finger tracking accuracy and lag, as well as audio feedback latency, may also become significant impediments as content density is increased (Adelstein, 2003). Voice recognition features appear very well suited for use in this context and do much to reduce user confusion and frustration in comparison traditional mouse and keyboard systems, however the voice training required to create a functioning user profile would not be easily accomplished with visual impairment

While bimanual exploration is achieved using the Fuse-Map system, it is interesting to note that most participants preferred to explore the magnetic element of the interface with their dominant hand while using their non dominant hand for tactile and kinesthetic exploration and spatial referencing. This was contrary to the expectation that participants would prefer to engage the magnetic features of the interface with both the dominant and non-dominant hand.
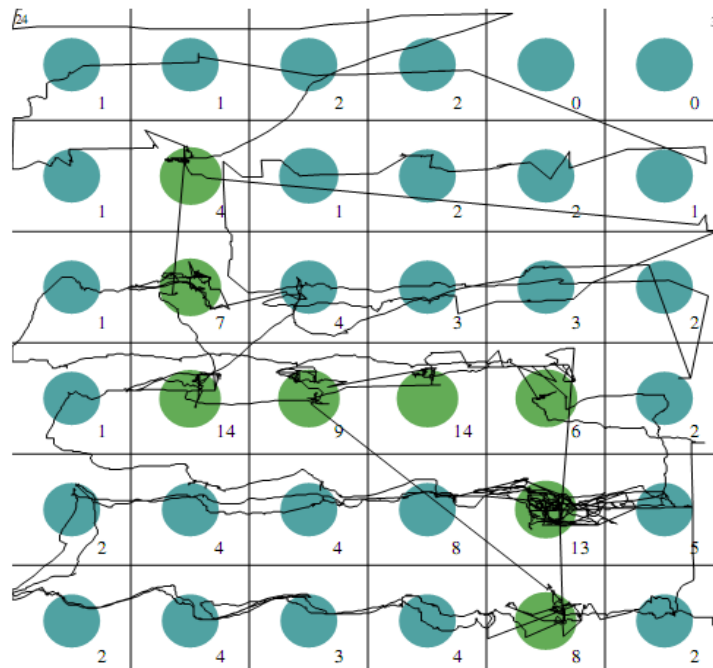

Figure 2: Screen shot of test scene depicting target points in green and finger/cursor movement paths as black lines.

Participants noted that the raised line border surrounding the 'display' area provided a very useful frame of reference that influenced their exploration strategies. As most

participants employed a very linear exploration strategy by moving their hand laterally across the grid [See illustration in Figure 2] the static tactile border provided a conspicuous cue to return back across the next row. Many participants also used their non-dominant hand to estimate distances or position of target points relative to the border in condition one tests. This suggests that it may be possible to develop a technique for scale estimation using the non dominant hand for reference measurements.

Conclusion:

An initial round of participant trials has successfully demonstrated the validity and feasibility of the Fuse-map concept in principle. While user testing of the Fuse-map system remains ongoing, initial proof-of-principle trials in a laboratory setting indicate a high potential viability for this platform as a truly low cost, robust approach for establishing universal access to geographic products. When presenting coarse cartographic data (i.e. a simple pattern of points within a grid), information can be conveyed as well, if not better, than by traditional tactile maps and virtual reality devices. Furthermore, the ease with which new patterns can be displayed and volume of feature attribute information that can provided also far surpasses the parameters of traditional tactile maps. The most valuable next step for further research in this vein will be to determine what the information density and resolution limitations of the Fuse-Map interface may be. The development momentum for visual applications experienced by many of the component technologies used in this prototype is also a significant boon to this research. Early adoption of these technologies will help create a more inclusive and integrated research and development community and stimulate an awareness of the need for integrated approaches to universal access. Still, significant further investigation and development effort will be needed to determine the extent to which unproven technologies like refreshable magnetic displays are effective mediums for more complex geographic content.

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