A Commentary on the Use of Touch for Accessing On-Screen Spatial Representations: The Process of Experiencing Haptic Maps and Graphics

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The growth of the Internet and the digital revolution have meant increased reliance on electronic representations of information. Geospatial information has been readily adapted to the world of cyberspace, and most Web pages incorporate graphics, images, or maps to represent spatial and spatialized data. But flat computer screens do not facilitate a map or graph experience by those who are visually impaired. The traditional method for compensating for nonvisual access to maps and graphics has been to construct hard-copy tactile maps. In this article, we examine an electronic accommodation for nonvisual users—the haptic map. Using new and off-the-shelf hardware—force feedback and vibrotactile mice—we explore how touch can be combined with virtual representations of shapes and patterns to enable nonvisual access to onscreen map or graphic material. Key Words: digital representation, haptic maps, visual impairment.

Introduction

Haptic maps and graphics are the electronic equivalent of traditional tactile maps and graphics. As we become more immersed in a new technological age where electronic communication is paramount, the barriers associated with the digital divide (Waddell 1999; Warf 2000) take on critical significance for those interested in spatial or spatialized information. For geographers, digital representations on-screen have added a new dimension to cartography and to geospatial representation generally by permitting dynamic representations (e.g., animations), simultaneous visualization and analysis, on-screen overlay and dissolve, and other features (many of which have been captured in GIS packages). But, just as hard-copy, pen-and-ink maps had disadvantaged those who were visually impaired, thus eventually encouraging the development of tactile maps and graphics, so too today, there has arisen a need to incorporate nonvisual modalities (such as a sense of touch or audition) into interfaces to enable nonvisual access to geospatial representations. In this article we explore one such effort—the creation of haptic maps based on force feedback and vibration.

First, the question arises as to what contribution haptic maps and graphics can offer. In addressing a parallel question, the Commission on Tactile Maps and Graphics for the Blind and Visually Impaired (part of the International Cartographic Association [Wiedel 1983]) suggests that tactile representations can provide access to nontext information in a form that is amenable to both visual and nonvisual interpretation. The Commission also suggests that these maps are a potentially valuable educational tool that represents information that otherwise may be inaccessible and that they are a way of increasing geospatial awareness. These advantages (identified initially for hard-copy tactile maps and graphics) appear to be equally viable motives for stimulating research and analyses in the electronic domain.

In this commentary, we begin with a discussion of the properties of touch. Such an under-
standing is needed to appreciate the types of interfaces that have had to be developed to enable the use of touch to explore on-screen maps, diagrams, and images.

**Map-Relevant Attributes of the Sense of Touch**

Geography has a long history of developing and using tactile representations (Wiedel 1983; Tatham and Dodds 1988). Many cartography labs have 3-D relief maps and globes that illustrate topography and other environmental and physiographic features. It is generally accepted that tactile maps and graphics add an extra dimension in addition to the location-based attributes of 2-D flat maps, namely, naively adding sensations from touching that could add to the understanding of shape and pattern, but little attention has been paid to the fact that “touch” has several different components. In this section, therefore, we examine the traditional concept of tactile sensing of hard-copy maps and diagrams and then proceed to an in-depth examination of the overarching concept of “haptics.” The latter is the medium that we suggest is most useful for providing access to electronic (on-screen) maps and graphics via touch.

**Touch**

Tactile senses are usually associated with cutaneous perception or touch upon the skin (involving any part of the body). Although most often experienced via a fingertip or the palm of a hand, researchers have explored the interpretability of touch on the back, the stomach, arms, legs, and other parts of the body’s skin. There are three fundamental neural inputs required in touch. Cutaneous receptors involve just the skin (e.g., the fingertip). Kinesthetic receptors involve muscles, tendons, and joints (e.g., as in the arm). Haptics involves combining inputs from both the previous two sensory modes, as in sweeping the hand across a three-dimensional surface. The first two of these modalities are essentially sensory phenomena involving direct sensation. Haptics is generally associated with cognitive and memory processes (e.g., recording the “feel” of the texture and plasticity of a rubber ball). While the visual system extends across all scales from nanoscale to universal, haptic sensing is restricted to an area immediately surrounding the body (i.e., the touchable arena).

Haptics are often used to explore the geometric properties of objects, including tactile maps. Because of the integration of cutaneous and kinesthetic processes, haptics sometimes lead to systematic distortions resulting directly from the effects of moving the body parts used in exploration (e.g., mistaking the amount of force being exerted).

Klatzky and Lederman (2002) defined the body parts used in *active* and *passive* dimensions of touch, with active kinesthetic perception and active haptic perception being the two in which motor control is exerted over the touch process. These two types are the ones most relevant to examination of on-screen haptic maps. We now examine what are these active and passive perceptions.

The subjective sensations of touch include pressure, spatial acuity, and position. Other sensory experiences, such as exposure to heat, cooling, and pain, while providing sensory information that sometimes is useful in object recognition (e.g., recognizing an ice cube), have, at this time, no demonstrated usefulness in terms of on-screen maps or graphic interpretation and will not be discussed in this article.

Given this brief overview of those aspects of touch of greatest potential use for on-screen haptic exploration of maps and image-based digital representation, the question arises as to exactly what are haptic maps. A haptic map involves not only cutaneous or tactile sensation but force applied through the hands, wrists, arms, and shoulders. Haptics is thus a dynamic concept. It combines touching, feeling, pushing, or pulling, or other means of exerting force. Again, a relevant question arises: why is there a need for maps that have to be explored in this manner?

While paper maps remain in widespread use, a steadily increasing proportion of map information can be found in the electronic domain. Digitized maps and graphics represent an efficient way to store geospatial data while simultaneously providing a means for representing, analyzing, and interpreting map and graphic information. These attributes are being tapped for visualizations on Web pages and for a variety of situations involving the Internet (e.g., Location-Based Service Information). But, material thus represented is intended largely for visual inspection. While the visual sense is accepted to be the most powerful spatial sense and is admirably suited for representation and evaluation of
geographic data, its use denies access to maps and graphics by visually impaired people (those blind, vision-impaired, or low-vision people of varying ages—particularly, an increasing proportion of elderly people represented by aging baby boomers). According to the Braille Institute (2004), there are about 15 million visually impaired (blind and legally blind) people in the United States, and it has been estimated that there are about 82 million people in the United States who have low vision (i.e., require technical assistance such as eyeglasses or contact lenses for viewing or reading). With more and more information relevant to daily life as well as to knowledge about local, national, and world events being presented in electronic form, this raises a serious ethical problem: are visually impaired people to be denied access to electronically represented geospatial information? This ethical question is receiving more attention as the slowing of aging processes and increased life expectancy of the baby boomers ensures that more and more people will enter age groups where visual impairment is common. For example, more than 70 percent of people aged 65+ are likely to have a visual impairment, and, as the baby boomers age and life expectancy improves, this group will represent an increasingly greater proportion of the total population! How will these populations be able to access important information (such as location of goods and services) that explicitly requires the use of vision?

Haptic Maps and Graphics

There are two primary properties of haptic sensing that are relevant for creating haptic maps and graphics (Klatzky and Lederman 1993). At the highest level are two components: the geometric properties of objects, and the material properties of objects. The former are specific to particular objects, such as size and shape. Geometric properties of haptics can be subdivided into micro and macro types. The fingertip is an example of a micro-, geometric-level receptor, the hands or limbs as the sensing process at the macro level. As opposed to this, material properties are differentiated into texture, hardness, and temperature. Texture includes properties such as roughness, stickiness, weight, and curvature.

How can we use this information to create haptic maps and graphics designed to help ameliorate the problem of a widening digital divide? To help find an answer, it is necessary to turn to the idea of virtual systems and, to some extent, to the innovations made by the video game industry. In particular, attention can be directed toward the use of haptic mouse interfaces—particularly those using force feedback and vibrotactile experiences to enable image interpretation or perception of shape, pattern, and density characteristics of phenomena on maps, and size, height, slope, and continuity features on graphics. To further explore these features, we now summarize the features of interfaces that allow haptics to be used for on-screen map and graphic exploration.

Haptic Interfaces: Force Feedback

Joysticks and Haptic Mice

The last decade has seen the development of a number of force feedback computer interfaces. These range from the Logitech Wingman® Force Feedback Mouse (Figure 1) to the “Phantom®,” a high-end haptic interface device that allows a person to feel and interact with virtual three-dimensional objects. The Phantom’s® stylus can be used, for example, to trace the curvature of a virtual object to determine what it might be (e.g., a virtual ball). As a cutting-edge device, this product has been demonstrated only sparingly for object shape and texture definition, and its potential for exploring maps remains to be investigated. Now a discontinued item, the Logitech Wingman® Force Feedback Mouse was designed for adding haptic feedback to computer games and for customizing a Microsoft Windows interface with haptic feedback. A selection of vibrotactile mice has been developed recently, including the Logitech iFeel™ Mouse (Figure 2) and a nearly identical vibrotactile optical mouse produced by Hewlett Packard. Both of these mice produce very small and modest buzzing or vibrational sensations when the mouse is triggered by some event on the computer screen. Both of these mice are currently available off the shelf and are sold mainly to computer users who want to augment the traditional visual display with extra effects.

Haptic interfaces are inexpensive and readily available as commercial products. They have different advantages and disadvantages in terms of their potential for enabling interpretation of electronic map and graphic representations. For guiding nonvisual users around spatial infor-
information, the frame of reference becomes critical. A conventional computer mouse only registers a user’s relative movement, a scrolling motion, thus permitting a user to become “lost” within a nonvisual scene. A device with a fixed or controllable frame of reference, such as the Wingman mouse, a touch screen, or tablet, and some gaming joysticks facilitate the translation of an interface frame of reference to that of the representation. Although there remain significant interface issues of scale and zooming, the fixed frame of reference devices are, at present, the optimal way of accessing the inherent benefits of the flexibility of digital information. In general, multimodal interfaces are becoming of increasing importance in many applied areas of information access, including geospatial information processing, due to three main factors: (1) substitution—providing nonvisual access to digital spatial information when vision is not available because of sensory loss; (2) augmentation—adding additional information through another modality, such as representing the accuracy of a scene simultaneously through vision and audition; and (3) redundancy—providing multiple renditions of the same information that can be tailored to the specifics of the users’ interface (Web, PDA, or full GIS) or to the needs of the user from child to adult, novice to expert.

Immersion Corporation (http://www.imersion.com [last accessed 22 October 2004], San Jose, California) has developed a broad range of haptic devices and technologies in partnership with companies in the fields of computer gaming, computer-aided design and manufacturing, automotive controls, industrial controls, heavy machinery, medical equipment, surgical devices, and video editing systems. These devices are geared primarily toward the consumer and industrial market, with prices ranging from under $30 to several thousand dollars. The Logitech Wingman® Force Feedback Mouse (Figure 1) uses Immersion Corporation T ouchSense® technology to provide force feedback. In general, these devices are designed to augment an existing interface or to allow users to gain finer motor control and sensation in situations where the visual focus is occluded (such as the technology for endoscopic surgery instruments) or in situations where the visual focus is occupied with a critical activity (such as driving a vehicle or operating an industrial machine). In these settings, appropriate haptic cues can allow the user to complete complex tasks without the full visual focus or by augmented vision with haptic feedback.

SensAble Technologies (http://www.sensable.com [last accessed 22 October 2004], Woburn,
Massachusetts) offers a wide range of haptic interface devices and software, including the Phantom®, a high-end haptic interface device that allows for interaction with three-dimensional objects through a stylus held in the hand. The Phantom® is commonly used in the scientific research community for complex 3-D model exploration tasks and virtual object modeling and has gained widespread acceptance for its ability to reproduce a wide range of haptic effects within a significantly large range of motion. SensAble Technologies also produces an advanced developer tool kit for use with its haptic interface devices. SensAble Technologies’ haptic devices, such as the Phantom®, are being diversified and redesigned so that they can be sold more readily to consumers at lower prices. To this point, they are found primarily in research settings with significant budgets for computer hardware.

In terms of use for interpreting electronic map and graphic representations, both the Phantom® from SensAble Technologies and the haptic mice with Immersion Corporation’s TouchSense® technology are appropriate, but they have different strengths. A primary advantage of the Immersion Corporation haptic mice is their affordability and ease of use, which would allow them to be used by nearly anyone capable of very simple hardware and software installation. A drawback of the Immersion Corporation devices is that they generally lack the physical range of motion (approximately the range of motion of the hand and wrist) to provide high-quality feedback over a large spatial area necessary for exploring an electronic map display. Inevitably, the user is required to explore the electronic map display within a small physical space, which reduces the amount of detail that can be sensed. Haptic devices with a physical range of motion similar to that of the whole arm (e.g., the Phantom® Premium 3.0 Haptic Device) are more suited to exploring an electronic map display due to the amount of detail that can be communicated through haptic cues over the full range of motion associated with the whole arm. An additional consideration in determining the appropriateness of a haptic device for a particular map display application is whether the device operates in a two-dimensional framework associated with a traditional desktop (such as the Immersion Corporation mice) or whether it operates in a three-dimensional framework (such as the Phantom®). The exploration of a map display with haptic cues may be best done in a two-dimensional framework, as the cognitive tasks associated with adding and integrating a third spatial dimension may be difficult, particularly for blind or visually impaired users. Most electronic maps currently used as a basis for tactile displays or haptic displays are traditional two-dimensional maps and may be more suited for exploration by a haptic device that delivers haptic sensory cues within a two-dimensional framework.

How Well Can Haptic Maps and Graphics Be Used?

Basic shapes are used on maps and graphics to represent complex, symbolically real-world objects (e.g., on topographic sheets, squares may represent houses; crosses represent churches; crossed lines may represent a railroad; parallel lines may represent a road or river). The process of reading and understanding a map or graphic involves recognizing the symbol, correctly identifying its shape, and then making the correct associative link to the real-world object. A major design challenge in creating haptic maps and graphics is determining what shapes or icons can be easily identified through touch and then forming the necessary generalized symbolization structure to represent the real-world objects. There is a parallel problem when dealing with auditory maps, where sounds may replace touchable shapes (Golledge, Loomis, and Klatzky 1994, 1998; Krygier 1994). Griffin (2001) has contributed some important ideas on symbolization for haptic maps, and much of the works of Bentzen and Peck (1979), Andrews (1983), Vasconcellos (1996), Hardwick, Furner, and Rush (1996), and Hardwick et al. (1997) on this and related topics is readily transferable to the electronic domain if the symbols can be interpreted via a haptic interface. The authors of this article have completed some preliminary tests to determine which basic shapes are easily identifiable through touch (Rice et al. 2004). These authors conducted preliminary tests in 2000 and 2001, and more elaborate tests in 2003 and 2004, to evaluate how well individuals could identify basic shapes using a haptic mouse connected to a standard personal computer. Forty-two participants explored six basic shapes (square, circle, rectangle, cross, bar, triangle).
without any visual feedback, using only a haptic mouse to make a shape identification. We found that participants could identify these six basic shapes at a level far greater than that associated with a null hypothesis of random guessing. Participants made correct shape identifications 66 percent of the time using only haptic feedback delivered through a haptic mouse. Note, however, that when simple auditory cues were added to the haptic feedback depicting the shape, participants made correct identification of shapes, on average, 73 percent of the time. These results support suggestions made by Krygier (1994), Golledge, Loomis, and Klatzky (1994, 1998), and Weber (1998) that adding an auditory component to maps is also a promising new area and could be more beneficial than adding haptics alone. For example, Rice et al. (2004) further found that combining touch and audition (i.e., a multimodal interface) was even more successful in symbol shape identification. Evidence thus has begun accumulating regarding the value of nonvisual interfaces for on-screen map or graphic representation, but little is available in terms of an overview of what the haptic sensation implies and on its potential usefulness for geoscientists. In the next section, therefore, we explore further the task of using force feedback as an interface to examine on-screen symbols and shapes without the use of vision.

**Force-Feedback**

There are two principal interface types that have potential for the haptic exploration of geographic maps: force-feedback and vibration. We now deal with each in turn, commenting on their relative effectiveness when compared with vision. For example, Rock and Harris (1967) reported that vision dominated haptic percepts when subjects judged the size of a square that was simultaneously felt and viewed through a reducing lens. This early result has been reproduced many times (Klatzky and Lederman 2002). The relative dominance of sight and touch has been explored by perceptual psychologists for decades (Lederman, Thorne, and Jones 1986; Loomis and Lederman 1986). Invariably, it is agreed that in the geospatial domain, generally, vision is the dominant sense. Additionally, researchers in psychology have examined the usefulness of various symbolic patterns for their discriminability (Heath 1958; Nolan and Morris 1971; Bentzen 1972; Jansson 1972; Edman 1992), as have cartographers Flannery (1971), Slocum (1983), Andrews (1983), Olson and Brewer (1997), Eriksson (2001), and Tatham (2001). The relative contribution of different modalities is often modulated by attention (Klatzky and Lederman 2002).

Force-feedback provides a haptic effect when using a vibrotactile or force-feedback mouse. In the following summary, we detail the principal facets of force-feedback; parenthetical numbers refer to elements illustrated in Figure 3.

- **Virtual Wall:** A virtual wall is a line of “force” used to define a shape in a virtual domain. Virtual walls can be used to define boundaries or outlines of shapes (e.g., buildings). When a mouse cursor contacts a virtual wall, the user must exert extra force to pass through the wall. Otherwise, the cursor can be guided along the wall to reveal (or trace) a shape. This allows the user to detect different regions of the screen surrounded by walls or borders. For example, Rice, Jones, et al. (2003) have defined Virtual Walls around all buildings depicted on a map of the University of California Santa Barbara campus. Using a force-feedback mouse, each building can be located and its shape identified and learned (see http://soundscapes.geog.ucsb.edu, UCSB Campus Map v2. 0b).

- **Gravity Well:** A Gravity Well attracts a cursor in its vicinity, potentially identifying an entrance (e.g., to a building) or a window (e.g., to access a menu). When the cursor enters the active region of a gravity well, it is physically drawn through, say, a gap in a virtual wall toward the center of a virtual object. Thus, objects with gravity wells (e.g., an on-screen map object identifying the states of the United States) can enable the user to find specific states.

- **Multiple Virtual Walls:** Areas of a geographic scene have multiple virtual walls applied to convey texture in the force-feedback equivalent of visual stippling. This allows the user to detect different regions of the screen, an important property when dealing with polygons.
depicting (or defining) specific geographic regions.

- Rubber Banding: [4]
  Objects with the rubber-band effect have a springlike feel so that it is easy to remain on the object while performing mouse clicks or moves (e.g., operating map objects, buttons, or slider bars in a desktop environment). This also can be used with a notchlike effect with a buffer region around a spline, bezier, or similar geometrical curve. These effects have the potential to facilitate a user following a sinuous feature such as a road or geographical boundary. While force-feedback provides a link to objects defined by linear boundaries or linear graphs, much information on maps is contained in differently sized and shaped polygons. Irregular polygons (such as water bodies or urban areas) are difficult to identify just from a boundary trace for object definition. Using other haptic properties (such as a vibrating interface) may prove more effective for such tasks. Thus, we now turn from our examination of force-feedback for identifying geometric properties of objects to a vibration-based interface that can identify material properties of features.

**Vibration**

Two-dimensional and three-dimensional features may be perceived as having material properties that are relevant to a class of features, not just to an individual one (such as specific object shape as of a building). In a cartographic sense, density shading may be interpreted as a material property that can be perceived in a number of different places on a map where density (expressed, perhaps, as a class interval) is similar. In such cases, haptic perception is macrogeometric, for the same pattern could be experienced and/or identified at different places by a similar vibrating feature. Klatzky and Lederman (1993) define three significant properties of macrogeometric perception—hardness, temperature, and texture. In the case of haptic maps, texture is the attribute that can most commonly be used to represent phenomena.

Texture includes roughness, stickiness, and sharpness. Representing texture as a vibratory experience involves tapping an ability to recognize differences in the speed or frequency of spatially sensed indicators. A vibrotactile pattern is produced by repeatedly exposing part of the body (usually the skin) to pulses of similar or different frequencies. Vibration cues are transmitted to the skin receptors (usually the hand) via a vibratory mouse. Vibrations can convey impressions of roughness and help identify different patterns of phenomena. Thus, phenomena expressed by a class interval representing a specific range of magnitude of occurrence would have the same vibration frequency. Vibrations can be used as stand-alone indicators of feature occurrences or as complements to other senses, particularly vision. But, as a stand-alone indicator of the presence of a phe-

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**Figure 3** Diagrammatic illustration of haptic effects.
Note: Numbers refer to previous descriptions in text. Solid arrows indicate direction of force applied. Source: Adapted from Jacobson, Kitchin, and Golledge (2002, 394).
nomenon, perceived roughness appears to be the dominant component of texture.

The roughness property is more useful in portraying surface properties than geometric shape (but it can be thus used when perceiving filled shapes). Haptics can be used in early (gross) identification of objects to enable early processing such as simple shape identification. But they are also used to enable higher-order processing so that object features can be determined. Haptic perception focuses at first on a restricted set of attributes (such as vibrations); then, a search is undertaken for tangible features (such as roughness or sharpness). While sharpness is point related, roughness is more of a surface property. In cartography, spatial variations in the density of phenomena are traditionally represented as choropleth maps or as “painted” isopleth maps—the former often are used to represent density variations in discrete areal units according to some predefined class interval limits, and the latter use density shading to represent changes in continuous phenomena such as slope or temperature (Monmonier 1982; Monmonier and Schnell 1988).

In the haptic domain, roughness replaces two-dimensional density shading of a visualization (based on color, the grayscale, or symbol structure). Using roughness to enable haptic perception usually invokes different symbols (e.g., dots, stippling, diagonals, open and closed geometric features, and so on [Andrews 1983]). Bentzen and Peck (1979), Frank (1992), and, more recently, Eriksson (2001) provided lists of symbols that could be clearly used in the touch domain (e.g., raised lines, raised parallel lines, different-sized dots, raised diagonals, various striplings). When presented as raised three-dimensional symbols, they can provide the appropriate variations in surface properties that facilitate haptic interpretation.

Limitations When Using Haptic Maps: Illusions in Touch

As with vision, illusions are a significant feature compromising the value of touch. One of the most common (and underappreciated) is the vertical-horizontal illusion. This illusion implies that vertical lines are overestimated relative to length-matched horizontal lines. This means that haptic perception of factors such as the vertical and horizontal dimensions could be distorted and that experiencing things like distances on x and y coordinates could also be distorted.

Yet another illusion relates to the comparison of obliques with verticals and horizontals. Greater difficulty is found in estimating properties of obliques (Loomis and Lederman 1986; Klatzky and Lederman 2002). In addition to illusions, other problems relating to touch include the influence of positional change of limbs and effectors during sensing (e.g., distance of the user’s body from the mouse) as well as the amount of applied force that the searcher or explorer uses. At this stage, few if any of these concerns have been investigated in the domain of haptic maps, although Rice, Jacobson, et al. (2003) have examined vertical versus horizontal shape recognition in terms of the effectiveness of using force-feedback to interpret on-screen shapes.

Combining Touch and Sound (Haptic Soundscapes)

Interactions between information presented in different modalities are complex. When combining touch and audition, Jacobson (2002) and Griffin (2001) suggest that there are four potential relationships:

- they operate independently
- haptics predominate
- sound predominates
- haptics and sound interact in complex ways (for example, in relationship to interference, redundancy, and augmentation)

Acknowledging these possibilities, Jacobson (2000, 2004) focused on combining touch and sound to produce an effect termed Haptic Soundscapes. This concept uses a force-feedback mouse and auditory labels or directions (e.g., when navigating a screen or searching for a specific location) to give a mixed modal interface that allows more comprehensive feedback about on-screen features (for examples, see http://soundscapes.geog.ucsb.edu [last accessed 22 October 2004]). Other researchers are finding similar results (e.g., Jansson 1999; Oviatt 1999).
Future Directions

Human-computer interfaces are evolving as technology advances. Spurred by success in the video game industry and by innovation in medicine and health sciences that use simulations, virtual systems, and remotely controlled robotic techniques to diagnose and treat certain types of patients, there has been a universal move encompassing nanotechnology, biotechnology, information technology, and cognitive technology (NBIC) to consider the relative advantages and disadvantages of multimodal interfaces (Golledge 2003).

In geography, exploration into how maps and graphics can be widely accessed from Internet sources is an ongoing research area. In this article, we have explored the idea of using touch to help examine and interpret on-screen maps and graphics. There is a growing literature on multimodal interfaces that seeks to restrict the growth of a digital divide that would result from the exclusive use of visualization as the mode for electronically representing and displaying the huge quantities of maps, graphics, diagrams, and images that need to be accessed from digital databases.

There appears to be considerable evidence that the computer industry is very interested in the potential of multimodal interfaces (Roco and Bainbridge 2003). Annual workshops are being held to explore how government, business, and academe can cooperate in imagining, developing, marketing, and using new representational modes (Roco and Bainbridge 2003). Because spatial thinking, reasoning, and representation are universal across the sciences, arts, and humanities, there appears to be abundant opportunity for geographers to contribute to these developments. The profession’s interest and expertise in visualization and spatialization can be extended by exploring how the domain of touch (and audition) can be incorporated (via interfaces such as haptics and auditory mapping, for example) into this nationally prominent research arena. Such efforts may help to represent and display more complex and varied information sets than is currently the case. In doing so, geographers not only join other professionals in defining new avenues for research, building new products, and perhaps developing more integrative theories and models of the complex multidimensional world in which we live, but also address the ethical and practical problems associated with universal accessibility to processed geospatial information that at present seems to be enlarging an unwanted digital divide.

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