LINKED AUDIO REPRESENTATION IN CYBERCARTOGRAPHY: GUIDANCE FROM ANIMATED AND INTERACTIVE CARTOGRAPHY FOR USING SOUND

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ABSTRACT

This paper discusses sound representation in cybercartographic atlas projects and products as one example of the application of multisensory representation in contemporary cartography. Auditory representation, like animated and interactive visual cartography, makes explicit use of the temporal dimension. Educational multimedia studies have argued that effective learning outcomes result from the coordinated interpretation of visual and auditory information and from the cognitive relations that learners develop within and between their mental representations of these materials. Based on this previous work, this paper examines the goals and motivations of research into animated and interactive cartography to determine which of those could or have been applied to the use of sound as a media for linked abstract representation in which meaning is conveyed both by the content carried by each sensory mode as well as by the manner of relations between visual and auditory representations, signified by the coordinated reactions of the visual and auditory components of atlas products to user actions. To illustrate key concepts in this discussion, the paper describes an application prototype that allows a user to examine data concerning Canada's trade with world regions using an audio-visual interface. The paper outlines a set of functional roles that this type of linked auditory representation could fulfill within an audio-visual cartography, drawing on functional analyses of interactive and animated cartography and acoustic analogies developed through the analysis of the motivations and goals of dynamic visual cartography.

Keywords: cybercartography, multisensory cartography, audio-visual, linked auditory representation, dynamic legend.

1. INTRODUCTION

This paper discusses sound representation in cybercartographic atlas projects and products as one example of the application of multisensory representation in contemporary cartography. The approach discussed here is the result of an analysis of the motivations and goals that guided the development of animated and interactive visual cartography, based on the understanding that animation and interactive computer applications share an explicit temporal dimension with sound, and an assessment of which of those goals and motivations can be applied to the use of sound in the context of computer-based and World Wide Web-distributed cartographic representation. This approach is proposed as one of possibly multiple perspectives on the use of sound in conjunction with cartography.

Mapping products and cartographic processes incorporating sound along with visual components (e.g., map graphics, images, and text), although being developed on an experimental basis by artists, multimedia designers and cartographers, still constitute a small proportion of contemporary mapping efforts. Recent Internet applications and World Wide Web page design technologies, such as Google Maps (TAYLOR, 2005a), enable the use of audio as one among many forms of media annotations on maps. The resulting audio 'mash-up' maps are widely available through the Internet. Citizens, artists, activists, journalists, planners, and private companies are now able to mix sound with maps for many different purposes. These possibilities are radically transforming the design, distribution, use, and perception of maps incorporating sound.

Examples of maps incorporating sound in conjunction with visual maps have been developed over at least the last two decades as an outgrowth of research into animated and interactive cartography and GIS. In these examples, sound has been used as a means to provide narration explaining the function of a map or a multimedia interface (MONMONIER, 1992; KRYGIER, 1994; HARROWER, 2003); as a means to draw a user's attention to a visual map component (HARROWER, 2003); as an abstract language providing a set of variables (pitch, tempo, timbre, etc.) that can be used to add information to a thematic map without over-complicating the visual display (KRYGIER, 1994; FISHER, 1994); as media to be accessed through the map, alone or as part of a video or an animation (HU, 2003); as a means to alter the message of a visual map through the spatialization of related auditory information (BRAUEN, 2006); and as a means to reinforce and contextualize the thematic content of an atlas (CAQUARD et al., forthcoming). These examples of cartographic sound use also indicate alternative theoretical perspectives and approaches with, for example, KRYGIER (1994) adapting cognitive-cartographic perspectives on dynamic visual displays (DIBIASE et al., 1992) to abstract sound use and CAQUARD et al. (forthcoming) examining the theory of sound design for cinema and computer games to derive approaches for cartographic sound use.

The work described here was conceived in the context of cybercartographic atlas projects. According to TAYLOR (2003, 2005c), cybercartography is defined as the organization, presentation, analysis and communication of spatially referenced information on a wide variety of topics of interest to society in an interactive, dynamic, multimedia, multisensory format with the use of multimedia and multimodal interfaces. The paradigm of cybercartography emphasizes the process of mapping and the resulting maps as central to the information era as artefacts, as conceptual metaphors and as organizational frameworks for digital information based on location. Among the major elements of cybercartography (TAYLOR, 2003), the following are particularly relevant to this discussion:

- Cybercartography is multisensory using all major human senses rather than just vision as is the case with traditional cartography. Human perception is intrinsically multisensory and as RODAWAY (1994, 35) argued, "all geographical experiences are made up of a complex of sensuous information combining activities of the sense organs, the body and its limbs, and mental processes." Similarly, people use all of their senses in learning situations, often balancing and intermixing stimuli across sensory modalities without being consciously aware of it. Providing learning materials through different sensory modalities can provide people with a choice of learning styles or combinations of learning styles.
- Cybercartography uses multimedia formats and new telecommunication technologies, such as the World Wide Web. Location is used, at least metaphorically, to relate information but representations include a variety of forms including text, videos, graphs, photographs, tables, statistics, models, voice commentary, music, virtual and augmented reality and live Web camera images. As technological advances continue new formats will emerge.
- Cybercartography is user-centric, interactive, and engages the user in new ways. Effective teaching and learning takes place best when individuals are actively involved and engaged. In co-ordination with engaging map users via multiple senses, cybercartographic atlas projects attempt to combine theoretical perspectives on sensory modalities and user evaluations of the atlas products developed by the projects to assess the effectiveness of the methods adopted.

Based on experiments with learners using contemporary, predominantly visual and auditory educational media, MAYER and ANDERSON (1991, 1992) argued that effective learning outcomes require that perceived verbal information, whether read or listened to, be incorporated along with visual information into mental representations containing verbal information, mental imagery, and referential linkages between the two. Thus an examination of sound uses within cartography should also include a consideration of the visual aspects of that practice and should attempt to understand the integrated use of both modalities. Because effective audio-visual map designs require the co-ordinated engagement of a user's hearing and vision, an examination of how and why dynamic visual cartography systems have been designed should assist in understanding the requirements for designing such systems to include both sound and visual displays.

Although audio-visual cartography is still only a partial step in the direction of this larger vision of multisensory cybercartography, the practicalities of incorporating sound into computer-based, network-distributed maps and atlases are now sufficiently understood (BRAUEN, 2006; BRAUEN and TAYLOR, 2007; CAQUARD et al., forthcoming) to allow researchers to focus beyond the technologies to examine theoretical questions related to audio-visual cartography and to evaluate the understandings and perceptions of users of these mapping products. Although the work described here was conducted in the context of cybercartographic atlas projects and the use of sound as a representational media for spatialized information follows directly from the multisensory and multimodal emphasis of cybercartography, the use of sound outlined below is an appropriate extension to other conceptions of contemporary cartography such as multimedia cartography (CARTWRIGHT et al., 2007), maps for Internet distribution (PETERSON, 2003, 2008), and interactive cartography (ASCHE and HERRMANN, 1994; DORLING, 1992; PETERSON, 1995).

The discussion in this paper is limited to the consideration of computer-based representations incorporating pre-recorded or composed sounds used in co-ordination with visual elements consisting of text, images, and graphical elements, and more specifically presentations with cartographic components. These types of representations are suitable for use with either stand-alone or network-distributed maps and atlases and can also be seen as an extension of a type of representation examined by earlier literature on animated and interactive cartography which may have, but generally did not, include the use of sound.

Within this context, experiments incorporating sound are certainly not new but the literature on the cartographic uses of sound is sparse and there is as yet little guidance concerning ways in which sound can be effectively used or even guidance concerning which purposes sound can most effectively serve. KRYGIER (1994) examined possible uses of sound in conjunction with cartography as enabled by computer technology and, although he discussed the use of narration and mimetic sounds, he focused in particular on the definition of a set of abstract sound variables such as pitch, timbre, location, and duration that can be manipulated to encode data associated with visually-mapped geographic locations. FISHER (1994) demonstrated the use of one of these abstract sound variables (duration) to highlight data uncertainty within a cartographic display. Sound has been used as an added dimension in GIS to provide qualitative and quantitative information for studying noise abatement policies (MÜLLER and SCHARLACH, 2001; SERVIGNE et al., 1999) and to create a traffic as noise World Wide Web visualization of Madrid automobile traffic, projecting an explicit authorial perspective onto the underlying traffic flow data (THIRION, 2007). Multimedia cartography (CARTWRIGHT et al., 2007) incorporates audio and video clips, still images, animation, and text into dynamic cartographic products, often using the map as an interface providing access to the multimedia content. Examples of multimedia cartography that incorporate sound include Wula Na Lnuwe'katiyek, an atlas of Mi'kmaq places and stories (FRANCIS, 1996), Introduction to Iqaluit, a set of maps combining imagery and place name pronunciations (MOUAFO and MÜLLER, 2002). GARTNER (2004) discussed the use of handheld mobile Internet devices to assist pedestrian navigation by issuing redundant spoken-word directional commands that compensate for situations in which a user may be focused on other tasks or when circumstances make reading the screen difficult. THÉBERGE (2005) argued for multimedia atlas designers to consider sound early in the overall process of atlas design because visual and acoustic design elements each affect the interpretation of the other. CAQUARD et al. (forthcoming) examined sound design for cinema and computer games as sources of guidance for cartographic sound design within projects in which the sound design was conceived, in part, to enhance and highlight the narrative character of the atlases and the potential of that narrative to encompass multiple perspectives.

This paper is structured as follows. Section 2 reviews literature concerning cartographic research into first animated and then interactive visual cartography. Section 3 discusses linked auditory representation in cybercartography, describes a prototype application that allows a user to examine data concerning Canada's trade with world regions to illustrate the discussion, outlines auditory metaphors to guide the use of linked auditory representation, and discusses the application of these metaphors to a classification of functions for interactive cartography. Section 4 briefly discusses the implications of this research and provides some preliminary assessments of the results of user evaluations that have been conducted with the trade data browser application.

2. BACKGROUND: CARTOGRAPHIC RESEARCH

Although sound has not been ignored in research concerning the applications of dynamic media to cartography, as outlined above, the focus has unsurprisingly been on visual dynamics; animation and interactive visual cartography have been the predominant focus, although tactile and audio-tactile maps have also received attention (GOLLEDGE, 1991; JACOBSON, 1994; SIEKIERSKA et al., 2003; RICE et al., 2005). Focusing on the visual, there has been considerable research concerning both animated (THROWER, 1959; DORLING, 1992; MONMONIER, 1992; PETERSON, 1995), and interactive (MONMONIER, 1989; CRAMPTON, 2002) cartography as means to enhance cartographic processes beyond the static map. Much of the motivation for this research has been the desire to redirect cartography from the goal of developing, understanding, and verifying the single best map for a given cartographic application. Rather the new goals included providing the map user with the ability to quickly examine a variety of views each of which may provide a different perspective on the mapped data, and to use the dynamic aspects of the new presentation techniques as a means of highlighting change in the mapped data or as a means of comparing different data.

Sound is occasionally mentioned as a promising addition to the techniques of dynamic cartography (THROWER, 1959; MONMONIER, 1992; PETERSON, 1996) but a systematic focus on the use of sound appears to have been rare. Furthermore, there appears to have been no examination of cartographic sound usage that asked whether or not some of the models and metaphors that have been adopted by researchers working on the visual aspects of animated and interactive cartography could be applicable to sound. This could be a potentially fruitful perspective to pursue. Indeed, like animated cartography, sound and hearing explicitly use a temporal dimension and in computer-based applications, although sound can be used as a background accompaniment, it is fairly common for the application to respond by altering the playback of sounds as a user works with different parts of the design. Therefore this section examines research into animated and interactive cartography in order to answer the following questions. What has been the motivation for the different presentation models developed in the research concerning animated and interactive cartography? What metaphors and models have emerged from this research and which, if any, of these are applicable to the use of sound in audio-visual cartography?

In designs that include interactive sound components, the currently predominant model of human-computer interaction is that of a visual display, keyboard and mouse. This requires that the sounds be manipulated indirectly through user actions directed at the displayed visual elements such as graphics, text, and images (for a discussion that details the audio-visual interactions of one such set of technologies see BRAUEN, 2006). More recent research and standards development is attempting to support voice and touch-tone initiated computer and web interactions (CHRISTIAN et al., 2000). Throughout the remainder of this paper, the indirect model of interaction with sounds via visual components is assumed. Note that this assumption does not influence the design of the sounds or visuals in any way — any type of sound (e.g., recorded audio containing vocal narrations, sound effects, music, or a combination and any musical composition supported by the installed synthesizer sound banks and computational power of the user's computer) could be included in such a design. It is generally assumed that both are designed with the other in mind in order for them to work well together.

2.1 Animated Cartography

Animated cartography has been a topic of research since at least the 1950s (THROWER, 1959; CAMPBELL and EGBERT, 1990). The appeal of animation for cartographers is the ability to represent spatiotemporal processes using the dynamic character of certain media such as film or computer displays. Although techniques such as arrays of multiple small maps or the use of isarithms have been developed to represent processes of change, especially temporal change, in static cartography, the animated map presents a sequence of images at a sufficient rate for the represented phenomena to be perceived as a spatial process rather than as a sequence of snapshots. According to PETERSON (1995, 6), the use of animation draws on humans' abilities to detect visual change and movement which are possibly more developed than our abilities to recognize static images. "In a sense, what happens between each frame is more important than what exists on each frame" (ibid., 48).

Models of cartographic animation have been developed from the perspective of how each successive frame is created and then assembled into an animation (PETERSON, 1995) and from the perspective of technologies that can be used to create the animated sequence (GERSMEHL, 1990). The latter classification provides greater detail but the underlying models are the same as those outlined by PETERSON (1995, 143–152): frame-based or cast-based. Frame-based animation uses some means of creating a set of final images for each frame of an animation which are then assembled into a sequence, possibly in conjunction with audio. Early cartoon motion picture animation was framed-based. A series of maps showing the expansion of a city's urban boundary at one-month intervals assembled into an animated sequence would be a cartographic example of frame-based animation.

Cast-based animation uses a cast of visual objects which move independently of a stationary background (or a series of stationary backgrounds representing different scenes). Each cast object is called a cel because the original techniques of cast-based animation implemented each independent object as a sequence of images on celluloid that were pegged onto the background image for photographing. The complete cast was assembled on the background for each frame using layers of celluloid. Although the original photographic technique did create a series of final images that were sequenced, contemporary computer-based animation software, such as Adobe Flash or the World Wide Web Consortium's (W3C) graphics specification language Scalable Vector Graphics, maintain the layered object model both in the authoring metaphors and in the final presentation of the graphics to the viewer. Television weather maps are a common example of cast-based cartographic animation in which weather phenomena such as wind, rain, and cold fronts are implemented as cels over a stationary map image. MONMONIER (1992) discussed the use of graphic scripts to present thematic spatial data in a manner that treated the map, associated bar charts, and statistical plots as synchronized cels.

Although animation is most commonly employed in cartography to demonstrate process change over time, other orderings of animation have also been proposed. DIBIASE et al. (1992) used the term re-expression to denote the presentation of an animated sequence in an alternative ordering or using an alternative pacing of the animation other than presentation time as a linear scaling of phenomenal time. The ordering could be based on the values of a represented spatial variable (e.g., hurricanes ordered by severity of annual impact) or could use an altered pacing of the sequence in which the duration of each section of the animation is derived from a variable (e.g., the total number of hurricanes within a region during the time depicted). TAYLOR (1987) sequenced the display of literacy levels (as classified percentages of the population) for India's states so that the outline of India was thematically filled in as groups of states assigned to descending classification levels were coloured on the map. Re-expression may provide additional opportunities for the viewer to determine whether or not spatial patterns exist in the data.

MONMONIER (1992) proposed techniques that quickly change a cartographic visual display to draw a user's attention. The first, blinking, in which one or more symbols on the display were flashed for a period of time, he found useful in drawing a user's attention to specific items on the display. Another technique, subsequently referred to as flickering, alternately displays a pair of spatial variables mapped over the same area to allow a viewer to look for patterns of correlation between the two variables. "Because quasi-movement reflects dissimilarity, the overall degree of visual dissonance is inversely proportional to correlation" (ibid., 252). PETERSON (1996) extended flickering to more than two variables by sequencing city-level maps showing a set of related variables by district (percentages of population by age group).

Although re-expression and flickering are usually used to show process change over a fixed spatial extent, other applications of animation vary the spatial extent alone or in combination with changing the thematic content of the map. Fly-through animations (MOELLERING, 1980) alter the viewpoint, often in conjunction with a simulated three-dimensional surface to emulate the experience of flying over a terrain.

PETERSON (1996) proposed animations using sequences in which the mapped data remained unchanged but the cartographic representations changed to highlight the decision processes in cartographic abstraction and to offer additional opportunities for the viewer to detect patterns as the representations are changed. Although some of these animations could be used with a fixed spatial extent — for example, a sequence of maps showing the effects of different data classification schemes in choropleth mapping — others also include changes in the spatial extent. As an example of this latter category, PETERSON used the term cartographic zoom to refer to animations in which selection and symbolization change as the scale of the displayed map either increases or decreases. As is commonly done with static cartography, the selection criteria change along with the scale allowing more types of information to be included in the map as the scale increases. Similarly, map features that can only be shown as points at small scale may be transformed into areas as the map zooms in to a larger scale. In recent years, this technique has become familiar to the general public through applications of Google Earth such as visual backdrops for television weather and news reports or computer-based geographic mash-ups.

KRAAK and KLOMP (1995), summarizing DRANSCH (1995), described additional variations on the idea of animating a sequence of changing cartographic representations such as the use of different symbolization types (e.g., isoline, dot density, and choropleth). Additionally, they discuss animations using successive build-up in which the sequence of images is designed to show a fixed spatial extent while thematic layers are individually added to the display in an attempt to help the viewer understand spatial context.

2.2 Interactive Cartography

MONMONIER (1992) stated that most people who saw the prototype implementing his graphic scripts wanted the ability to pace the presentation, reverse the direction of animated sweeps, and review introductory sections. Thus, computer-based cartographic animation was one motivation for the addition of control mechanisms allowing the user to decide when, and how often, they viewed portions of a cartographic representation. But other factors such as the relative expense of producing paper maps at a variety of scales to examine particular spatial phenomena compared to viewing maps on dynamic computer displays also spurred research into interactive controls. DORLING (1992, 217) argued that interesting spatial patterns often exist at very large scales and "rapidly blur away as the spatial scale of analysis is reduced", requiring interactive tools, such as pan and zoom, to allow adjustment of the extent of the mapped area. The declining cost and broad availability of computer technology in the 1980s also prompted research into the use of computers for the analysis of large data sets, spatial and otherwise (DORLING, 1992; CRAMPTON, 2002). Interactive techniques developed for statistical analysis were adapted for spatial analysis — geographical brushing (MONMONIER, 1989) being one such adaptation.

MONMONIER (1990) examined approaches to the analysis of time-series data ranging from static maps and charts to the use of interactive computer displays. He argued that, compared to static maps and graphs, interactive mapping and charting using dynamic computer displays offers a promising alternative for dealing with the complexity that arises in data sets comprised of multiple variables observed periodically at a number of locations.

ASCHE and HERRMANN (1994, 217) examined the possibilities of utilizing digital technologies not only for map production and design but also for publication and use. The dynamic use of the map as an interactive interface, they argued, would support the "integration of time-based data, of animation, and sound" and the inclusion of interactive controls would allow not only the cartographer but also a user to experiment with alternative cartographic representations.

MONMONIER (1994), building on his earlier work on graphic scripts, argued that there are two main metaphors guiding the development of animated and interactive cartography: navigation and narration. Navigation is apparent in software interfaces that allow a user to locate images and other information about places, regions, and spatial relationships. The user directs the system to narrow, broaden, or adjust the visual display to satisfy a desire for information. Narration, by contrast for MONMONIER, is apparent in system functions that operate by playing out a sequence of information for a user based on a predefined script. "The presentation is narrative rather than navigational because the user is now a comparatively passive viewer, who watches while the system …controls the sequence of scenes" (ibid., 202). According to this analysis, he divides the uses of digital mapping systems into navigational or narrative based not on the underlying information-seeking actions of a user but instead based on whether the user or the computer is more in control. As an example, he argued that a user may navigate a data set using geographic brushing or may watch a graphic narrative as the system drives the geographic brush using a predefined sequence. Although this dichotomy seems very difficult to apply to the complexity involved in the use of computer mapping systems, the analysis does highlight the temporal context involved in the use of interactive mapping systems. There is a sequencing, perhaps better conceived as a dialogue, as a user directs the navigation, requests feedback on where the navigation has thus far led him or her in the geographic investigation, and plans the next steps for furthering that investigation.

KRYGIER et al. (1997), CRAMPTON (2002), and PERSSON et al. (2006) defined typologies of interactivity for the presentation of geographic information, each with a different purpose and resulting details. KRYGIER et al. (1997) proposed a typology of multimedia element types for use in the development and delivery of post-secondary courses in large lecture halls using computers and overhead projectors. The typology categorized multimedia content to be used as part of a lecture according to function, describing how the instructor intended to present and pace the delivery of information for which the multimedia content was an aid, and form detailing a range of predominantly visual presentation materials. This is similar in intent to multimedia typologies that have been used for training multimedia designers by encouraging them to consider alternative types of media and different abstractions for the ideas presented (HELLER and MARTIN, 1995, 1999). The range of forms considered by KRYGIER et al. is both more detailed in explicit consideration of alternative graphic forms and more restricted because it ignores explicit consideration of text and sound within the taxonomy except when included as part of an encompassing form.

CRAMPTON (2002) proposed a typology of interactive user functions, intended as a basis for comparing the level of interactivity supported by geographic visualization systems, and included the following functional categories:

- Interaction with the Data Representation: The user manipulates the system to produce different views of the underlying data. This could entail, for example, changing the cartographic representation used in maps, selecting additional feature types (often implemented as visual layers) for display, listing all or a selection of attributes associated with some or all mapped features, or adjustment of the displayed map extents.
- Interaction with the Data: The user queries and filters information from the system database to focus the presentation of information for the geographic investigation being conducted. Techniques such as geographical brushing and highlighting may be used to draw attention to the results of the queries and to assist a user in determining the next steps in the investigation.
- Contextualizing Interaction: CRAMPTON, drawing on MONMONIER (1992, 1994), argued that when using a digital mapping system, the "user's decision-making and choices are conditioned by what the user has already learned and what they still …would like to know" (ibid., 88). Although his general discussion of this idea explicitly included the temporal ordering of a user's interactions with the system and the understanding that, for at least some of these interactions, only some orderings make sense, the category he proposed for the typology is more restricted. In this category he included interactions that provide multiple simultaneous lenses on the data being examined: multiple map views, each using different representations or created using different database queries; or the interactive linking of the map displays to different types of graphic displays, such as statistical charts, so that operations such as geographical brushing simultaneously highlight the data of most recent interest in all linked displays.

- Interaction with the Temporal Dimension: The user interacts with dynamically changing (animated) maps or other graphic displays, with the possibility of controlling the sequencing of the displayed data representation (e.g., ordered by time period, or through the use of flickering or re-expression, as described in Section 2.1). CRAMPTON also grouped fly-throughs and navigation in this category.

PERSSON et al. (2006) proposed an alternative typology to CRAMPTON although their goal to assess the level of interactivity provided by different geographic visualization applications was similar. For this discussion, key features of each of these typologies are:

- the focus on the ability of users to query data and focus geographic displays on subsets of information relevant to a current information need;
- the focus on the ability of users to link multiple representations of the data together, building

on earlier techniques such as geographic brushing; and

- the focus on the temporal aspects of a user’s interactions with the application, either because of the dialogic structure of a user’s interactions with the system or because of the inherently temporal characteristic of certain display techniques such as animation and flickering.

More recently, ANDRIENKO et al. (2005), ANDRIENKO and ANDRIENKO (2006), and KRAAK and VAN DE VLAG (2007) working under the disciplinary umbrellas of geographic visualization, geovisualization, and visual analytics have, along with other research thrusts beyond the scope of this paper, continued to focus on the use of interactive displays providing users with the ability to link multiple representations of data using visual and computational methods.

3. LINKED AUDITORY REPRESENTATION

This section outlines an analysis of possible uses of audio as a media for related or linked representations of data along with visual cartographic displays, using an analogy to the linked visual displays of interactive cartography. Like linked visual displays, linked auditory representations are used to provide information or perspectives concerning geographic features or regions as a user interacts with the application. The analysis is structured using Crampton’s functional categories (somewhat loosely) and includes many of the interactive functions outlined by CRAMPTON (2002) and PERSSON et al. (2006). To illustrate the discussion, an audio-visual cybercartographic prototype designed to allow a user to browse data concerning Canada’s trade with world regions is briefly presented.

The audio model supporting linked representation throughout this discussion is that of a multichannel sound mixer and software synthesizer allowing simultaneous playback of multiple audio recordings along with playback of a synthesized composition. Furthermore, the audio model allows independent control of each audio recording and the synthesized composition (e.g., stop, start, looping, volume, and stereo balance settings) and of each instrument within the synthesized composition (e.g., volume, mute, echo, reverb, scale transposition). A full description of the audio model is beyond the scope of this paper but has been described elsewhere (BRAUEN and TAYLOR, 2007) and has been released as part of the open-source Nunaliit Cybercartographic Atlas Framework (http://nunaliit.org).

To clarify, not all uses of sound in interactive, audio-visual cartographic systems can be thought of as linked with components of the visual display. Sound can be used in multimedia computer applications in ways that prohibit a user from altering the audio playback (except by stopping the entire multimedia presentation). For example, music, sound effects, or didactic narrations may accompany the other, usually visual, media forms presented to a user. Even these sounds may be related to a graphic such as an interactive play/stop/repeat control but, for the purposes of this discussion, it is assumed that these audio components are not related to any visuals of the presentation itself. Moving the cursor over or clicking on map areas, other graphics, or hyperlinked text does not modify or affect the playback of the sounds in any way. For the remainder of this paper, this type of audio element will be referred to as unlinked: there is no user-detectable relationship between the audio and the graphic elements of the presented material. KRYGIER (1994) and MONMONIER (1994) both proposed the use of unlinked explanatory narratives. CAQUARD et al. (forthcoming) proposed cartographic sound designs based on an examination of sound designs for cinema and computer games and included discussion of unlinked uses of sound. Drawing on documentary traditions such as voice-over narration (NICHOLS, 1985), an unlinked sound is probably best understood as relating to the entire visual presentation currently before the user.

By contrast, a linked sound relates to the visible element(s) the user is currently ‘touching’ and both the manner of linking (i.e., how the audio and visuals to which the audio is linked behave in response to user actions) and the content of the audio may be used to understand the combined audio-visual representation. Linked auditory representations may be used to sound out additional variables associated with the currently selected feature or region. As a user works with different elements of the visual presentation, the sounds may change in a variety of ways: overall sound volume could be adjusted, volumes of individual sound elements (e.g., a narration or a specific instrument in a musical composition) could be adjusted, playback of the entire audio design or of individual elements could be stopped, started, or restarted from the beginning. Linked narration could provide place name pronunciations as the cursor is moved over symbols on the map. Linked audio encodings of spatial variables could use the volume of music, voice, or sound effects to represent relative density for a measured spatial variable such as population density.

As KRYGIER (1994) proposed, auditory variables could be used to add additional spatial variables to an already complex map as an alternative to displaying multiple juxtaposed univariate maps. But through careful selection of sounds to be linked to the visual map representation the overall cartographic message can also be shaped for the user, using the added value (CHION, 1994, 5) that sound brings to images, through the use of sounds which may superficially appear to do no more than reinforce information present in another form in the visual display. Although concerns have been expressed concerning the cognitive value of delivering textually-encoded information as both spoken narration and written text (KULYAGA et al., 2004; VETERE and HOWARD, 2000), the purpose of the representations in relation to the topic may provide reasons to make information available to a user in formats that are, if not wholly redundant, at least overlapping in content. Considering only spoken narration and a written text, there are characteristics of the content, such as tone of voice and pacing, that are only available in an audio recording while the written text may be easier for a user to work with in some contexts. When considering other auditory representation forms such as music or sound effects, the potential for Chion's added value may outweigh concerns of content overlap. Although overuse of redundant information in both visual and auditory forms may become tiresome for a user, there appear to be good reasons to consider including at least some redundant information in audio-visual cartographic presentations but more study of this is required.

3.1 Example: Interactive Trade Data Browser

Figure 1 shows a partial view of a World Wide Web application prototype designed to complement existing content in an atlas concerning Canada's Trade with the World (EDDY and TAYLOR, 2005) by allowing an interested user to browse measurements of Canada's trade with world regions using an audio-visual interface. Data observations can be selected representing the economic value of commodity exports and imports between Canada and regions of the world, aggregated geographically at approximately a continental scale and temporally to five-year periods. The data may be examined using top-level commodity sector categories — *Materials and Energy*, *Food and Agriculture*, and *Manufactured Goods* — or each of these sectors may be further classified showing finer-grained exchange values. As a user works with the browser, linked visual and auditory representations present the import and export measurements:

- Absolute exchange values may be selected for visual display by selecting a region, sector aggregation level, and five-year period and requesting that bar charts for the selection be displayed. A pair of charts, one showing exports and the other showing imports are displayed. The browser currently provides display space for up to three bar chart sets to be shown at once and a user may select each of the three bar chart sets according to any criteria.
- Relative exchange values are represented using *sonification*, the algorithmic representation of data through the use of observed data values to modify auditory parameters such as, for example, volume, register, or timbre (KRAMER 1994; for a discussion of sonification in a cartographic context see KRYGIER 1994). As a user works with the region selection map, two computed variables are represented using auditory variables:
  - *balance of trade*: for the current sector and time period selections, as the cursor is moved over map regions, the balance of trade with Canada for the currently highlighted region (Asia in Figure 1) is rendered sonically, computed as the ratio of Canada's exports to the region to Canada's imports from the region and broadly classified as "net imports", "balanced", and "net exports".
  - *value of exchange as a percentage of Canada's total trade*: for the current sector and time period selections, as the cursor is moved over map regions, the percentage that the highlighted region contributes to Canada's total trade is rendered sonically, classified as "low", "medium", or "high".

To help a user to understand these auditory representations, the browser combines auditory and visual feedback in response to user actions. As a user moves the cursor over the map, it is visually updated to display an outline of the currently highlighted region, and the region's label is displayed below the map. Additionally, as outlined above, the auditory representation of the region's balance of trade and of the region's value of exchange with Canada as a percentage of Canada's total trade is heard.

Much as the colours on a static choropleth map are normally explained through the use of a legend, some form of *dynamic audio-visual legend* function is required to allow users to isolate and learn the sound design representing an individual variable as well as to understand the combined representation of multiple variables. If a user selects the "learn/configure audio" tab shown in Figure 1, dynamic audio-visual legend components intended as training aids to help in understanding the browser's sound design are shown, along with the parameter selectors available in the default display. To simplify the overall visual display and reduce split attention affects (HARROWER, 2007), the design separates these aids from the default selector display with the intention that they not be shown once a user has become comfortable with the browser's auditory representations. Such a legend function is here proposed as an extension of earlier research concerning *active legends* for cartographic interactivity (PETERSON, 1999) and *dynamic legends* to accompany temporal animated sequences (KRAAK et al., 1997; BUZIEK, 2000). Here, the dynamic audio-visual legend fulfills two roles:

- As shown in Figure 2a, the dynamic legend is updated visually as the cursor moves over the regions of the map to assist a user in relating the simultaneously heard auditory representation to the two represented variables. In the diagram, Asia's trade with Canada for all commodity sectors during the period 1976–1980 is shown as balanced with a "medium" value of exchange relative to Canada's total trade.

- As shown in Figure 2b, the dynamic legend components may be directly used as audio controls to isolate the sounds associated with a single (sonified) variable. In the diagram, the cursor has been positioned over the "high" category of the value of exchange legend component. In addition to updating the visual display to provide feedback that the cursor action has been detected, this causes the sounds associated with the value of exchange variable to be adjusted appropriately for the "high" classification. The sounds associated with the balance of trade variable are not heard and, as shown, the visual display of the balance of trade legend component is cleared.

In addition to the sound features presented so far, the browser allows a user to "play" the set of displayed bar charts as a sequence, using the same sound design as used while interacting with the map. This allows a user to juxtapose the absolute exchange values shown in the visual bar charts with the relative measures of trade represented using audio and highlight that, for example, although the absolute exchange value of Canada's trade with a particular region may be going up steadily over time, the balance of trade with that region has changed or the value of Canada's trade with that region has changed relative to Canada's total trade. This sequenced auditory display strategy can be used, as suggested here with a chronological ordering of observations, such that playback time (the duration each observation in the sequence is played) represents a compression of phenomenal time (the actual five-year period represented) but not a reordering of those observations. Through re-expression, observations could also be sequenced to highlight other potential relationships in the data such as value-orderings of trade with different regions for the same time period.

This type of sequencing highlights that linked auditory representations must be differentiated from visual cartography displayed on a two-dimensional surface because a full two-dimensional display of features cannot be simultaneously represented in a coherent manner using only auditory representation. Instead, a sequential auditory representation requires some rationale for selecting features such that a linear (temporal) ordering is created from the (two dimensional) visually mapped feature set. This order could be determined by temporal or non-temporal (re-expression) scripts (MONMONIER, 1992), could be derived from virtual transects (COBURN and SMITH, 2005) which can be thought of as another form of linearized re-expression, or could be determined by user actions such as cursor movements (*interactive re-expression*). Visual feedback, possibly through dynamic highlighting of the feature(s) represented by the sound, is required to clarify the temporal (presentation-time) linking relation. Although the dynamic mapping of audio to represented features in the presentation temporal dimension may be one-to-one, it does not have to be. If only one parameter is being presented using auditory representation, for example, a sweep by value of the mapped features could be presented in which all of the features for which the parameter equals the currently represented value are visually highlighted to show/sound the spatial clustering (or lack thereof) of the measured phenomenon.

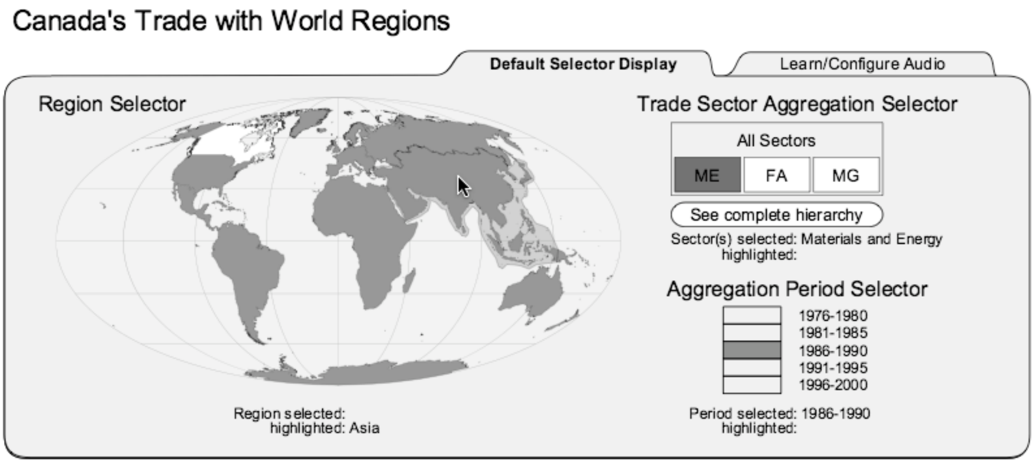

Fig. 1 - Trade Data Browser, default selector view. Semi-transparent outlining of Asia shows it is currently highlighted.

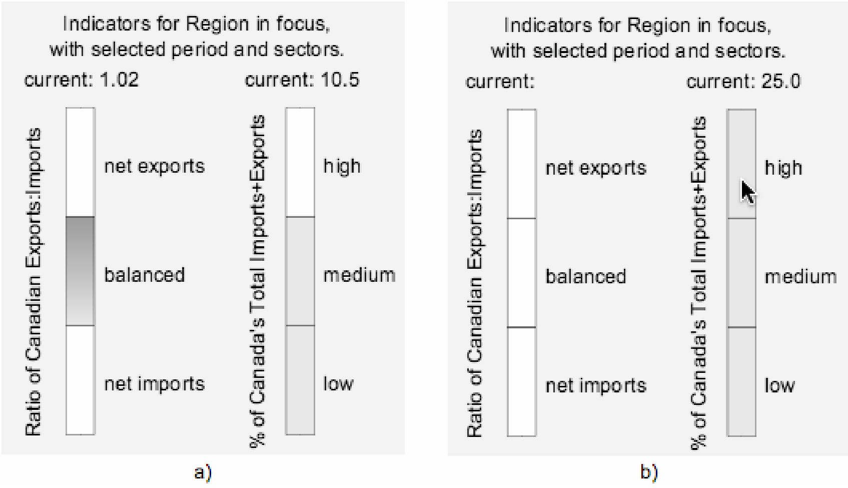

Fig. 2 - Dynamic audio-visual legend components: a) showing variables for highlighted region, and b) as audio controllers.

The current sound designs for the browser use either synthesized music alone or a combination of synthesized music and recorded audio. User-selectable sound design options, available in the "learn/configure audio" display, choose from among a set of synthesized compositions and associated control data that specifies what auditory parameters associated with each instrument in the composition are adjusted and how. One such audio design uses 16 measures from a lute prelude by Johan Sebastian Bach (BWV 997), played in a loop and controlled according to the current positioning of the cursor over the browser's region selector as outlined in Table 1. The controls specified for the synthesized composition use the cello and guitar parts together to voice the balance of trade variable. Metaphorically, balanced trade is represented by a balance of the two instrument parts while "net imports" and "net exports" are represented by one or the other of the two parts being muted. A synthesized drum track was added for the value of exchange variable with the volume of the drum track representing the "volume" of trade, measured by economic value; louder means more.

Some characteristics of this composition that led to its use as one of the browser sound designs include:

• The opening 16 measures that were used consist of consistent bass and melody lines which could be separated and assigned to different instruments allowing them to be controlled separately. Consistent here means that there were no lengthy pauses in either of the resulting instrument parts that could result in a misinterpretation on the part of an atlas user that, for example, the silence of the guitar part was related to the current position of the cursor rather than simply to a pause in the instrumental part.

• The two instrumental parts that result from the above separation are easy to follow because they differ in multiple auditory characteristics including: timbre (each instrument has a distinct sound), register (the cello follows the bass line while the guitar plays in a higher register), and tempo (the bass line tends to be slower than the melody line assigned to the guitar).

• The composition is in the public domain and a Musical Interface Digital Interface (MIDI) performance, compatible with the Nunaliit audio subsystem and music editing software needed to modify the piece for use in the browser, has also been placed in the public domain and is available for download from the Mutopia Project (http://www.mutopiaproject.org).

The portion of the sound design described above for the balance of trade variable is shown in Figure 3b. Figures 3a and 3c show additional design possibilities, each of which has been used in at least one of the selectable browser sound designs. The examples represent mapped variables using audio in which: a) scale transposition is used to adjust playback of a synthesized instrument into different registers to represent values of a nominal variable; b) the combined mute settings of a pair of instruments represent different states of a nominal variable (as described above); and c) the volume of a recorded sound effect (or other type of audio such as music or voice) represents the values of an ordinal variable. Note that compared to KRYGIER (1994) which recommends the use of sounds transformed by individual audio parameters (e.g., each of timbre or pitch individually) to encode data, the approaches shown in Figure 3 may use only one transformation parameter (a: register) or may use multiple (b: timbre, register, duration) by working with the structure of music. According to LEVITIN (2006, 73–80), many of these sound parameters are used together in the cognitive separation of sounds (e.g., identification of different sources of sound) and in the grouping of sounds (e.g., identifying a group of notes as being created by a single instrument). Gestalt principles apply to sound identification (GOLDSTEIN, 1999, 359–364). Using music in this way may then be more understandable for users but only initial testing has been done and none involving a comparison of different sound designs. The possibility exists that a user will need to decipher many sound events to identify those which actually signal a variable change with this type of encoding.

Linked audio designs such as those shown in Figure 3 require that the sounds be designed in a modular fashion so that individual auditory elements (e.g., a specific recording of narration or a snippet of birdsong) can be played, stopped, or have parameters of their playback adjusted (e.g., volume) based on the actions of a user. This type of design is analogous to cast-based animation with individual sounds, voices, or instruments being manipulated independently of other audio elements.

One of many alternatives that could be considered for linked audio is the use of (synthesized or recorded) voice to describe or 'read-out' information related to the feature to which the sound is linked. This use of sound would be similar to the use of narration and written text in conjunction with educational multimedia (MAYER and ANDERSON, 1991, 1992), was suggested by MONMONIER (1992), and would be an option worth considering when description of absolute values of parameters is important. Although this type of option is not ruled out for the remainder of this discussion, the main focus will be on the the use of audio-visual linkages as a means of signifying meaning rather than the use of audio content to impart meaning, whether that be in the form of language-like abstractions or extensional models of meaning within music such as associative meaning (BURKHOLDER, 2006). Obviously, connotation never sleeps and it would be possible and probably desirable to use sounds that relate to the subject matter being presented using both types of abstraction simultaneously.

Although some of these linking techniques have been tested and reported (e.g., scale transposition in KRYGIER 1994), some of these uses of audio require testing to understand how well these applications of sound meet users' expectations and how easily map users can understand the information. In general, users still do not expect mapped features to make noise and the perceptions of users when those features do so are not clearly understood. In the remainder of this section, we propose cartographic uses of sound as a linked abstract representation in which the relationships inherent in those linkages are intrinsic to the meaning of the combined audio-visual presentation, adapting the metaphors developed for animated and interactive cartography.

TABLE 1 - AUDIO COMPONENTS USED IN ONE SOUND DESIGN FOR THE TRADE DATA BROWSER APPLICATION.

auditory component	purpose in trade browser
Synthesized nylon string guitar	Balance of trade variable — "on" indicates either "net imports" if heard alone or "balanced" if heard accompanied by cello.
Synthesized cello	Balance of trade variable — "on" indicates either "net exports" if heard alone or "balanced" if heard accompanied by nylon string guitar.
Synthesized drum	Value of exchange variable: volume level indicates level of trade with louder indicating that the level of trade with the highlighted region is a greater proportion of Canada's total trade.

3.2 Guiding Metaphors and Functional Analysis

The following metaphors are proposed for the use of linked auditory representation as part of cartography, and as being analogous to the motivations and goals of the research into animated and interactive visual cartography outlined above. Obviously, careful consideration is required to ensure that a user can determine whether or not a specific metaphor applies to a particular presentation (or part thereof) and accompanying feedback (visual, aural, or both) is probably required to make this clear.

· Sounds are caused by events. Although this metaphor also underlies the next if you consider the way in which human hearing can become habituated to repetitious or common noises, in its simplest form this highlights that a certain set of sounds can be reserved for use only as alerts that something has happened or to draw a user's attention to a particular element of the visual or aural representation.

· Auditory change represents phenomenal change. As data associated with a different thematic selection (changing spatial or temporal criteria, for example) is presented, the linked sound representation should change only if the underlying information changes. Obviously, the parameter(s) of acoustic change being used as the basis of the auditory linking must be understood by the user. Dynamic audio-visual legends, as proposed above, should assist in explaining this to a user.

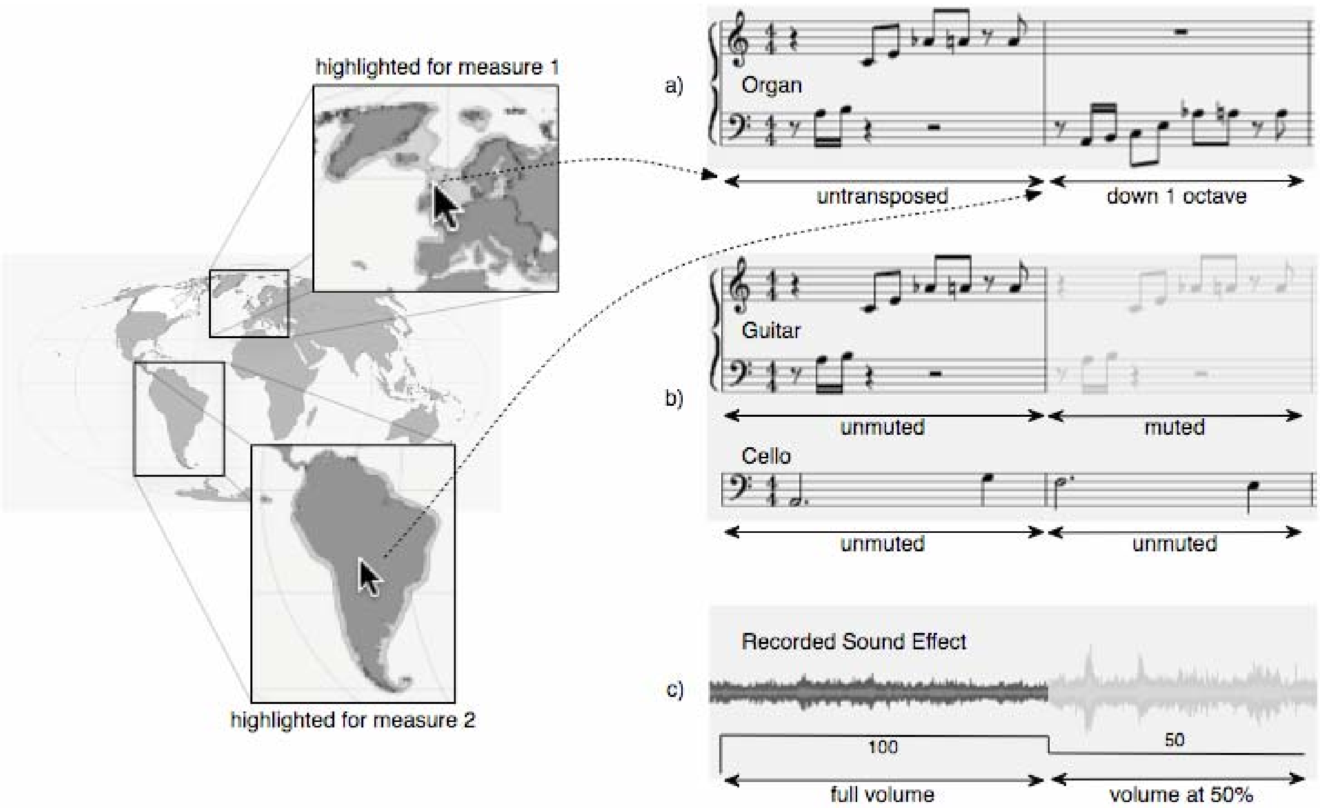

Fig. 3 - Linked audio: some design possibilities.

For this latter metaphor, the order in which observations are presented using auditory representation may be based on the metaphor of change over time with presentation time scaled to phenomenal time (such as, for example, with an animated, linearly-scaled timeline); or scaled according to some attribute of the underlying data (MONMONIER, 1992). Alternatively, the ordering of observations may also be re-expressed according to almost any criteria (DIBIASE et al., 1992, with respect to visual animation). But note the concerns of TVERSKY et al. (2002, 258) who argued that "there should be a natural correspondence between change over time, the core of animation, and the essential conceptual information to be conveyed …be [it] change over time, …temporal sequence, or causal flow." Careful design and user evaluations are required to ensure that users are able to learn and understand the basis of comparison in re-expressed presentations.

Table 2 provides a summary of functions drawn from the above review of animated and interactive cartography, grouped according to the functional categories derived from CRAMPTON (2002). For each function, the table indicates whether or not there is an analogy that could or has been applied to the use of linked sound in combined audio-visual cartography. Brief clarifications of each function follow, tagged with the function reference from Table 2.

TABLE 2 - APPLICABILITY OF VISUAL CARTOGRAPHIC FUNCTIONS TO LINKED ABSTRACT AUDIO.

Function	Applicable to Sound?
Interactions with Data Representation:	
R1) Navigational (pan and zoom) and map measurement functions	X
R2) Adding or removing mapped feature types (layers)	√
R3) Identifying meanings/legend function	fundamental (Sect. 3.1)
R4) Listing a set of parameters for a specified set of areas or features	√
R5) Listing all or additional parameters for a specified area or feature	X
R6) Comparing observed values to statistically significant values (e.g., maximum, minimum, mean, median)	√
R7) Modifying symbolization or classification method	√
R8) Emphasizing particular data through blinking	√
Interactions with Data:	
D1) Data Mining: extraction of data with specified characteristics	X
D2) Logical combination of data layers and generation of new variables	X
D3) Examination of data and of results of interactions with the data: cartographic cross-classification (brushing)	X
Contextualizing Interactions:	
C1) Linked displays	fundamental
C2) Many simultaneous views of data (small multiples)	√
C3) Dynamic comparison - multiple representations of data	X
C4) Dynamic comparison - representation of specified observations or of observations in specified orders (re-expression, and flickering)	√
C5) Dynamic contextualization - successive build-up	√
C6) 3D navigation or fly-throughs	√
Interactions with Temporal Dimension:	
T1) Dynamic comparison - representation of temporally-ordered observations	√
T2) Manipulation of dynamic variables (e.g., duration, period)	√
T3) Playback controls (e.g., stop, play, repeat) and manipulation of the time axis (stretching or compressing)	√

3.2.1 Interactions with Data Representation

In the context of computer-based multimedia, the navigational functions pan and zoom (R1) do not have obvious auditory analogies. Human hearing exhibits spatialization in the sense that the source of a sound can often be located relative to the hearer using only hearing. But the accuracy with which human hearing can locate sound sources varies, in part according to the relative location in three dimensions of a sound source compared to the location and orientation of the hearer (CARLILE, 1996). Similarly, map measurement functions do not have an obvious auditory analogy.

Adding or removing feature types or layers (R2) in the visual map may be done to understand the context of the data displayed or as a means of searching for spatial relations between different variables in a data set. Although these operations may often be accompanied by other analyses to determine whether or not, for example, a statistical correlation exists between variables, the addition of visual layers is analogous to the creation of additional, co-ordinated auditory representations. During subsequent examination of the map, for example through the use of interactive re-expression, a user can then attend to the correspondence of the auditory representations of some or all of the included variables. Do the representations tend to change in unison? The suspected relationship between variables may be used to select representations for variables to be compared to enhance that comparison. For example, using rising pitch or scale transposition on different instrument voices (e.g., violin and vibraphone) may highlight the regions in which the associated variables increase in unison or emphasize the lack of spatial correlation. Although the trade browser prototype currently presents two hard-coded auditory variables, the potential to experiment with the number of acoustically represented variables, or to temporarily silence some of those to allow a user to concentrate on a particular subset could be very useful.

Listing a set of parameters for a specified set of areas or features (R4) is an explicit use of a co-ordinated, generally tabular, display of additional data related to mapped features. As such, the use of co-ordinated auditory representations can be thought of as analogous to this in much the same way as discussed above for adding and removing layers. The idea of listing parameters for a subset of features, however, emphasizes a more automated approach to the subsequent examination than was suggested above (interactive re-expression). This suggests instead that the specified set of parameters be played according to a script for all of the specified features, with each feature being represented individually by the sonic representation of its parameters and all features presented in some understandable order: alphabetic by feature identifier, temporal order (if appropriate), or by increasing value of one parameter. Visual feedback indicating the feature(s) currently being represented would be essential to help a user keep track of the context. The set of features to be included in this sequential presentation could be explicitly selected by the user (possibly, but not necessarily, through the use of cartographic zooming) or could be comprised of all mapped features. The trade browser's ability to play the set of observations currently rendered by the visual bar chart sets is a rudimentary example of this type of capability.

Although listing all or additional parameters for a specified area or feature (R5) is not that different from listing the parameters for all features, in an auditory representation it is debatable how widely useful the presentation of one set of observations would be. For many people (those with perfect pitch notwithstanding), the auditory encoding of data yields a representation that is most useful for discerning differences or patterns rather than for ascertaining absolute values. Perhaps with sufficient training or a certain amount of innate listening ability, a person could discern information by listening to just the parameters associated with one feature but it is more likely to be useful as part of a sequence presenting the parameters for multiple features.

Comparing observed values to statistically significant values (R6) is an additional application of using sound to detect differences within a data set. This comparison could be conducted over time by playing the representation for an observation preceded or followed by the representation of the mean, for example. But this comparison could also be performed, at least for one or two variables, by simultaneously playing the statistical value as a separate sound encoding along with the presentation of a specific observation. This technique could also be used in conjunction with a presentation of sequenced observations; the statistical mean, for example, providing a steady accompaniment to each observation throughout the sequence.

As hinted at in Figure 3, there are a variety of design options for the use of abstract sound as part of audio-visual cartography. Undoubtedly, some representations will be more effective than others for presenting certain types of relationships but this may also be influenced by individual listening preferences and experience. Thus it would be ideal for a user of an audio-visual map presentation to be able to experiment with alternative sound designs (detailing the content of the sound as well as the manner in which user interactions modify those sound). This is the auditory equivalent of modifying the graphic symbolization (R7) for a map. All considerations for determining the distribution of the underlying data and the implications of that distribution for the choice of a classification method apply equally to auditory and graphic data representations, although further research into the ability of users to distinguish changes in sound (e.g., differences in sound volume or pitch) may indicate that some sound representations are effective for smaller (or greater) numbers of categories than is the case for graphic representations. Unlike graphic facilities for computers which have received large investments since the introduction of personal computers, thereby enabling mapping systems to provide default colour designs from which a user can select for a specific thematic mapping application, sound facilities are less uniform across systems. The creation of toolboxes for the creation and configuration of sound designs appropriate to widespread audio-visual cartography remains a significant future effort. The trade browser currently does allow a user to select from amongst a predefined set of sound designs for the representation of two auditory variables.

Emphasizing particular data through blinking (R8) does not have an obvious auditory analogy when considered with respect to the two dimensional role that MONMONIER (1992) proposed for visual blinking, although spatialized audio (even just using left-right stereo panning) could potentially be used, in coordination with vision, to guide a user to a relevant area on a map. Additionally, based on the metaphor that sounds are caused by events, temporal placement of audio alerts could be used to draw a user's attention to a particular data observation in conjunction with the ordered playback of a number of observations. For example, specific chimes could be used within an application to designate the observed minimum and maximum values during the playback of a temporal sequence.

3.2.2 Interactions with Data

Most of the functions listed as interactions with the data have no obvious auditory analogy. Data mining (D1) and operations to combine data layers (D2), although more appropriately thought of as logical operations than visual, often use visual methods based on interactions with the data representation to inspect the results of those operations. As discussed in Section 3.2.1, there are auditory analogies for some of the visual inspection methods that may be used in conjunction with the interactions with data.

Inspection methods, such as cartographic brushing (D3), relying on interactions with multiple abstract two-dimensional representations of the data have no obvious auditory analogies, although work has suggested that auditory displays, using pitch and volume, can be effective in conveying information concerning correlation of a single pair of variables in the form of a scatterplot (FLOWERS et al., 1996, 1997).

3.2.3 Contextualizing Interactions

As discussed above, linking a co-ordinated display to the map (C1) is considered a fundamental model for the use of linked auditory representation in interactive systems as proposed in this paper. Thus the technique of displaying multiple co-ordinated small thematic maps (C2) is analogous to the simultaneous representation of multiple variables using auditory representation, as outlined in Section 3.2.1. As a fundamental part of this perspective on cartographic sound usage, the ability of users to cognitively relate the sounds and the visual elements to which those sounds apply is obviously important and any inability to perform this feat would undermine the approach. But this ability on the part of interactive map users has been demonstrated by other research (KRYGIER, 1994; FISHER, 1994) and initial analysis of user evaluations concerning the trade data browser certainly showed no difficulties of this sort.

The technique from animated cartography of displaying a sequence of images showing changing cartographic representations, and thereby offering different perspectives on mapped patterns, may not have a useful auditory analogy. Although it would be possible to present multiple auditory representations of the same data (C3), the requirement to linearize the presentation of different observations using each encoding (see Section 3.1) as well as presenting each observation in different encodings would seem difficult to reconcile with the need to maintain an understandable context for a user. The ability of the user to understand such a display is questionable.

Dynamic comparison of specified observations or of all observations in specified orders (C4) seems like a very promising adaptation of graphic scripts (MONMONIER, 1992) and the auditory equivalent of visual re-expression (DIBIASE et al., 1992) based on the metaphor that auditory change represents phenomenal change. There are two approaches to this that would appear very useful: automated scripts for standard ordering such as value-ordered sweeps of an attribute for all features or temporal-ordered sweeps of timestamped observations of an attribute for a single feature; and user-selected orderings of observations. The first type of automated script may be useful for allowing users to easily run dynamic comparisons using commonly useful orderings. The second type, by contrast, gives a user more flexibility to focus on a smaller set of observations if desired. For example, selecting points at intervals along a marathon route and playing back the associated elevation values could be a quick means of evaluating the appropriateness of the terrain for the race. Alternatively, selecting a pair of observations and specifying that the auditory sequence should be played in a loop would create the auditory equivalent of flickering (MONMONIER, 1992): sonic quasi-movement now indicating change. MONMONIER also suggested alternative pacing of visual sweeps which would be applicable to the use of auditory representations: presentation of ordered observations at uniform time intervals or, to highlight clustering within the observations, presentation of ordered observations paced according to a linear sweep of the observed value range. The ability to play the observations corresponding to the current visual bar chart sets in the trade browser is a simple example of this capability.

The dynamic use of successive build-up (C5), although not serving the same purpose in auditory representation, could be quite useful as a means to allow a user to examine certain variables or subsets of the auditory encoding in isolation as a method for learning the auditory encodings or to focus on that subset during analysis. A dynamic auditory legend function, as discussed in Section 3.1, provides one means by which a user can access individual auditory encodings during training.

Spatialized sound could certainly play a role in conjunction with 3D navigation or fly-throughs (C6) and has been studied as a component, along with simple two-dimensional map-like graphics, of educational virtual reality systems (SÁNCHEZ et al., 2002). Lack of standardized media formats for the use of spatialized audio on the World Wide Web currently limit the use of this approach for browser-based cybercartographic applications. Without the requirement for spatialized audio, the technique of COBURN and SMITH (2005) for the definition of virtual transects on satellite images and subsequent playback of those transects provides an example in which combined audio-visual examination has been applied to specific routes across represented surfaces.

3.2.4 Interactions with Temporal Dimension

Similar to the discussion above of auditory re-expression (C4), the use of dynamic comparison using temporal orderings (T1) is a very promising use of auditory representation. Indeed, the explicit temporal dimension of sound perception makes the application of the temporal dimension for the ordering of auditory representation seem like an obvious choice. For example, by selecting suitably normalized trade flow observations between Canada and a specific region for different periods, a temporal sweep could be used to check for changes over time in the significance of that trading partner relative to Canada’s total trade or changes over time in the balance of trade between Canada and that trading partner.

The manipulation of dynamic variables (T2) such as duration and period for the auditory representation of sequenced observations could be used, as in visual display (DIBIASE et al., 1992), to stress, for example, periods of high activity. But duration must be used with care in displays such as this because the increase in playback time could make the auditory presentation tedious. Similarly, the use of playback controls and the manipulation of the time axis (T3) have obvious application in the control of auditory representations.

4. DISCUSSION

Although our proposals to include sound in cartographic applications have often been met with interest, some colleagues have responded with questions concerning what we think is missing from silent cartography or with questions concerning how sound could be used other than for didactic narrations and descriptive sound effects. In this paper, we have attempted to provide a partial answer to these questions based on an analysis of literature concerning visual animated and interactive cartography. We stress however that this is only one possible perspective from which the use of sound as part of audio-visual cartography could be examined. CAQUARD et al. (forthcoming) examined sound design for cinema and computer gaming and proposed uses for sound with cartography with the intention of highlighting and enhancing the narrative character of atlases and maps. Their perspective, we would argue, is largely but possibly not entirely complementary to that proposed here. As we argue above, there is no insurmountable contradiction between the use of linked audio as an abstract form of representation and the selection of sounds based on their content, possible connotative meanings, familiarity with an intended audience, aesthetic characteristics, or any of a number of other criteria. By drawing on the cartographic literature for the current study, the authors recognize the lineage of some of that literature as based on cartographic research projects designed to identify the least perceptible differences in static visual signifiers (BERTIN, 1983; ROBINSON, 1952; ROBINSON and PETCHENIK, 1976) and the application of that same perspective to dynamic visual signifiers (DIBIASE et al., 1992) and sound (KRYGIER, 1994). Although the desire to identify least perceptible differences within the different signifying systems is not necessarily problematic, it is clear that when humans listen to music or environmental sounds, the sounds they hear almost never change by varying only a single abstract sound parameter such as pitch, timbre, or attack time (LEVITIN, 2006). Thus cartographic designs based on a sound system designed to allow sounds to be modified according to individual abstract sound parameters would not necessarily provide users with a listening experience that they would consider *normal*. The approach adopted by the current study is then seen as a compromise that attempts to retain and use the structure of music or recognizable sounds in the abstract representation of information to provide a more usual listening experience while allowing for interactive control of that representation to signify linked abstract meanings. The trade-off from a user's perspective, as discussed earlier, is the possibility of having to listen to many changes in the sound stream before one that truly signifies a change in the underlying data.

Working with Human-Computer Interaction (HCI) researchers from Carleton's Human Oriented Technology Lab, map evaluation tests were conducted with participants selected from amongst students registered in first-year psychology courses. The evaluations were conducted in individual sessions with each participant working with several audio-visual map examples of which the trade data browser was one, although the selection and display of bar charts was disabled so the evaluations focused only on whether or not the participants could learn to work with the abstract use of the synthesized music to answer questions about the trade data. Each participant was specifically instructed to work with the "learn/configure audio" display first, and then to move to the default selector display (i.e., to hide the dynamic audio-visual legends) once they were comfortable working with the sounds. All participants used the sound design presented in this paper and the option to select different designs was disabled.

The evaluations were intended to provide basic information concerning the acceptance and understanding of the audio-visual map examples by the participants. With relatively little initial guidance, are map users able to understand how sounds relate to the visual elements in the examples? Do they understand the audio as being spatially related to the map (as in the case of the speeches in the election map and the synthesized music in the trade data browser)? If map users do require assistance, what assistance is required? Once map users understand the relationships between the audio and visuals, are they able to work with and understand the sounds? How do map users respond to maps incorporating sounds? Do they seem to like the use of sound?

Although the evaluation sessions have not yet been fully analyzed, some tentative statements can be made about the reactions of the participants to the trade data browser based on the initial research that has been done:

- Participants did appear to be surprised initially by the presence of sound in maps. But at least some appeared to accept the inclusion of sound quickly, although individual differences exist.
- Many participants appeared to be quite capable of working with music used in an abstract way to represent spatial variables. Some did not initially notice that the playback parameters (e.g., volume of the drums) were changing until this was pointed out to them. Some participants exhibited a lack of confidence in their ability to answer questions based on information presented using auditory representation despite, according to initial analysis, being able to do so.
- Individual variation in preference for working with sound seems to be considerable with some participants expressing interest in the trade data browser and others appearing to dislike the approach. Of course, the discomfort with (or acceptance of) the approach could also be based on design choices made with the trade browser rather than with the general idea of linked auditory representation.

Users' expectations for sound as part of an audio-visual cartography will be shaped by their experience with sound in other media, partly because of the relative paucity of audible cartography.

Additionally, with the growth of the World Wide Web as the primary medium for the distribution of maps (PETERSON, 2007) and its growth as a medium of exchange for music, movies, and games, the products of cartography are now distributed through a common channel with these other genres. Thus it is quite possible that expectations for the use of sound within the World Wide Web and from some of these other genres may transfer to cartography. Thus audio-visual cartographers should be aware of developments in these genres while continuing to base their craft on geographical and methodological approaches to cartography (KRYGIER, 1996).

Sounds are almost never simple and usually vary in many characteristics, such as timbre, pitch, duration, and tempo, all of which develop cultural associations over time. Adding the cultural understandings of the content that may be carried by a sound — for example, understandings of the event or source producing an environmental sound such as a bird song; the tone of voice and message encoded by a speaker; or knowledge concerning the composer and events around the production of a specific piece of music — introduce many possibilities for interpretation and connotation to work within the structure of an audio-visual map. The author's perspective must always be recognized and acknowledged in cartography (HARLEY, 1989) and the use of sound probably highlights this to an even greater extent.

Hearing and vision are different but complementary. As we argue above, hearing is probably not the appropriate modality to engage for *every* cartographic design problem and thus not every map needs sound. But as outlined in this paper, some of the motivations for animation and interactivity in visual cartography do suggest that sound could be a valuable complement to a visual dynamic cartography. Furthermore, we have outlined cartographic design objectives for which sound is a viable alternative to increased visual complexity. Research concerning the understanding and expectations of users of a combined audio-visual cartography and research to create tool kits to simplify the tasks of audio-visual cartographers remain substantial challenges.

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REFERENCES

ANDRIENKO, N. and ANDRIENKO, G. A Framework for Using Coordinated Displays for the Analysis of Multidimensional, Spatial, and Temporal Data. In STEFANAKIS et al. (2006), chap. 16, pp. 293–308.

ANDRIENKO, N., ANDRIENKO, G., and GATALSKY, P. Impact of Data and Task Characteristics on Design of Spatio-Temporal Data Visualization Tools. In DYKES, J., MACEACHREN, A. M., and KRAAK, M.-J., eds., Exploring Geovisualization, chap. 10, pp. 201–222. Amsterdam: Elsevier, 2005.

ASCHE, H. and HERRMANN, C. M. Designing Interactive Maps for Planning and Education. In MACEACHREN and TAYLOR (1994), chap. 12, pp. 215–242.

BERTIN, J. Semiology of Graphics. Madison: University of Wisconsin Press, 1983. Translated from the French by William J. Berg. Originally published in 1967.

BRAUEN, G. Designing Interactive Sound Maps Using Scalable Vector Graphics. Cartographica, vol. 41, no. 1, pp. 59–71, 2006.

BRAUEN, G. and TAYLOR, D. R. F. A Cybercartographic Framework for Audible Mapping. Geomatica, vol. 61, no. 2, pp. 127–136, 2007.

BURKHOLDER, J. P. A Simple Model for Associative Musical Meaning. In ALMÉN, B. and PEARSALL, E., eds., Approaches to Meaning in Music, chap. 5, pp. 76–106. Bloomington; Indianapolis: Indiana University Press, 2006.

BUZIEK, G. Legend Designs for Noninteractive Cartographic Animations. Computers and Geosciences, vol. 26, no. 1, pp. 21–28, 2000.

CAMPBELL, C. S. and EGBERT, S. L. Animated Cartography: Thirty Years of Scratching the Surface. Cartographica, vol. 27, no. 2, pp. 24–46, Summer 1990.

CAQUARD, S., BRAUEN, G., WRIGHT, B., and JASEN, P. Designing Sound in Cybercartography: From Structured Cinematic Narratives to Unpredictable Sound/Image Interactions. International Journal of Geographical Information Science, forthcoming.

CARLILE, S. Auditory Space. In CARLILE, S., ed., Virtual Auditory Space: Generation and Applications, Neuroscience Intelligence Unit, chap. 1–2, pp. ix–xiv, 1–25. Austin, Texas: R. G. Landes Company, 1996. ISBN 0-412-10481-4.

CARTWRIGHT, W., PETERSON, M. P., and GARTNER, G., eds. Multimedia Cartography. 2nd ed. Berlin: Springer-Verlag, 2007.

CHION, M. Audio-Vision: Sound on Screen. New York: Columbia University Press, 1994.

CHRISTIAN, K., KULES, B., SCHNEIDERMAN, B., and YOUSSEF, A. A Comparison of Voice

Controlled and Mouse Controlled Web Browsing. In Proceedings of the Fourth International ACM Conference on Assistive Technologies, pp. 72–79. New York, NY, USA: ACM, 2000.

COBURN, C. A. and SMITH, A. W. Musical Landscapes Using Satellite Data. In SPARK Festival of Electronic Music and Art. 3rd Annual Conference. University of Minnesota, Minneapolis, MN, February 16–20 2005.

CRAMPTON, J. W. Interactivity Types in Geographic Visualization. Cartography and Geographic Information Systems, vol. 29, no. 2, pp. 85–98, 2002.

DIBIASE, D., MACEACHREN, A. M., KRYGIER, J. B., and REEVES, C. Animation and the Role of Map Design in Scientific Visualization. Cartography and Geographic Information Systems, vol. 19, no. 4, pp. 201–214, 1992.

DORLING, D. Stretching Space and Splicing Time: From Cartographic Animation to Interactive Visualization. Cartography and Geographic Information Systems, vol. 19, no. 4, pp. 215–227, 267–270, 1992.

DRANSCH, D. Temporale und Nontemporale Computer-Animation in der Kartographie. Ph.D. thesis, Freie Universität Berlin, Berlin, 1995.

EDDY, B. G. and TAYLOR, D. R. F. Applying a Cybercartographic Human Interface (CHI) Model to Create a Cybercartographic Atlas of Canada's Trade with the World. In TAYLOR (2005b), chap. 22, pp. 517–540.

FISHER, P. F. Hearing the Reliability in Classified Remotely Sensed Images. Cartography and Geographic Information Systems, vol. 21, no. 1, pp. 31–36, 1994.

FLOWERS, J. H., BUHMAN, D. C., and TURNAGE, K. D. Data Sonification from the Desktop: Should Sound be part of Standard Data Analysis Software? In FRYSINGER, S. P. and KRAMER, G., eds., The Proceedings of the Third International Conference on Auditory Display 1996 (ICAD'96), pp. 467–472. 1996.

———. Cross-modal Equivalence of Visual and Auditory Scatterplots for Exploring Bivariate Data Samples. Human Factors, vol. 39, no. 3, pp. 341–351, September 1997.

FRANCIS, K. Wula Na Lnuwe'katiyek - an electronic mixed media atlas. Master's thesis, Carleton University, Ottawa, 1996.

GARTNER, G. Location-based Mobile Pedestrian Navigation Services: The Role of Multimedia Cartography. In International Joint Workshop on Ubiquitous, Pervasive and Internet Mapping (UPIMap 2004). September 7–9 2004. Available at http://www.ubimap.net/upimap2004. Accessed November 22, 2007.

GERSMEHL, P. J. Choosing Tools: Nine Metaphors of Four-Dimensional Cartography. Cartographic Perspectives, vol. 5, pp. 3–17, Spring 1990.

GOLDSTEIN, E. B. Sensation and Perception. 5th ed. Pacific Grove, California: Brooks/Cole, 1999.

GOLLEDGE, R. G. Tactual Strip Maps as Navigational Aids. Journal of Visual Impairment and Blindness, vol. 85, pp. 296–301, 1991.

HARLEY, J. B. Deconstructing the Map. Cartographica, vol. 26, no. 2, pp. 1–20, Summer 1989.

HARROWER, M. Tips for Designing Effective Animated Maps. Cartographic Perspectives, vol. 44, pp. 63–65, Winter 2003.

———. The Cognitive Limits of Animated Maps. Cartographica, vol. 42, no. 4, pp. 349–357, Winter 2007.

HELLER, R. S. and MARTIN, C. D. A Media Taxonomy. IEEE Multimedia, vol. 2, no. 4, pp. 36–45, 1995.

———. Multimedia Taxonomy for Design and Evaluation. In FURHT, B., ed., Handbook of Multimedia Computing, chap. 1, pp. 3–16. Boca Raton: CRC Press, 1999.

HU, S. Web-based Multimedia GIS: Exploring Interactive Maps and Associated Multimedia Information on the Internet. In PETERSON (2003), chap. 20, pp. 335–344.

JACOBSON, R. D. Navigation for the Visually Handicapped: Going beyond Tactile Cartography. Swansea Geographer, vol. 31, pp. 53–59, 1994.

KRAAK, M.-J., EDSALL, R., and MACEACHREN, A. M. Cartographic Animation and Legends for Temporal Maps: Exploration and/or Interaction. In Proceedsing of the 18th ICA/ACI International Conference, pp. 263–260. International Cartographic Association, 1997.

KRAAK, M.-J. and KLOMP, A. A Classification of Cartographic Animations: Towards a Tool for the Design of Dynamic Maps in a GIS Environment. In ORMELING, F., KÖBBEN, B., and GOMEZ, R. P., eds., Proceedings of the Seminar on Teaching Animated Cartography, pp. 29–37. International Cartographic Association, August 30 – September 1 1995.

KRAAK, M.-J. and VAN DE VLAG, D. E. Understanding Spatiotemporal Patterns: Visual Ordering of Space and Time. Cartographica, vol. 42, no. 2, pp. 153–161, 2007.

KRAMER, G., ed. Auditory Display: Sonification, Audification, and Auditory Interfaces. Santa Fe Institute Studies in the Sciences of Complexity. Reading, Massachusetts: Addison-Wesley, 1994.

KRYGIER, J. B. Sound and Geographic Visualization. In MACEACHREN and TAYLOR (1994), chap. 8, pp. 149–166.

———. Geography and Cartographic Design. In WOOD, C. H. and KELLER, C. P., eds., Cartographic Design: Theoretical and Practical Perspectives, chap. 3, pp. 19–33. Chichester; New York: John Wiley & Sons, 1996.

KRYGIER, J. B., REEVES, C., DIBIASE, D., and

CUPP, J. Design, Implementation, and Evaluation of Multimedia Resources for Geography and Earth Science Education. Journal of Geography in Higher Education, vol. 21, no. 1, pp. 17–39, 1997.

KULYAGA, S., CHANDLER, P., and SWELLER, J. When Redundant On-Screen Text in Multimedia Technical Instruction can Interfere with Learning. Human Factors, vol. 46, no. 3, pp. 567–581, Fall 2004.

LEVITIN, D. J. This is Your Brain on Music: The Science of a Human Obsession. New York: Dutton, 2006.

MACEACHREN, A. and TAYLOR, D. R. F., eds. Visualization in Modern Cartography. New York: Pergamon, 1994.

MAYER, R. E. and ANDERSON, R. B. Animations Need Narrations: An Experimental Test of a Dual-Coding Hypothesis. Journal of Educational Psychology, vol. 83, no. 4, pp. 484–490, 1991.

———. The Instructive Animation: Helping Students Build Connections Between Words and Pictures in Multimedia Learning. Journal of Educational Psychology, vol. 84, no. 4, pp. 444–452, 1992.

MOELLERING, H. The Real-time Animation of Three-Dimensional Maps. The American Cartographer, vol. 7, pp. 67–75, 1980.

MONMONIER, M. Geographic Brushing: Enhancing Exploratory Analysis of the Scatterplot Matrix. Geographical Analysis, vol. 21, no. 1, pp. 81–84, January 1989.

———. Strategies for the Visualization of Time-Series Data. Cartographica, vol. 27, no. 1, pp. 30–45, 1990.

———. Authoring Graphic Scripts: Experiences and Principles. Cartography and Geographic Information Systems, vol. 19, no. 4, pp. 247–260, 272, 1992.

———. Graphic Narratives for Analyzing Environmental Risks. In MACEACHREN and TAYLOR (1994), chap. 11, pp. 201–213.

MOUAFO, D. and MÜLLER, A. Web-based Multimedia Cartography Applied to the Historical Evolution of Iqaluit, Nunavut. In Proceedings of the Joint International Symposium on Geospatial Theory, Processing and Applications. July 9–12 2002.

MÜLLER, J.-C. and SCHARLACH, H. Noise Abatement Planning: Using Animated Maps and Sound to Visualise Traffic Flows and Noise Pollution. In Proceedings of the 20th International Cartographic Conference, vol. I, pp. 375–385. 2001.

NICHOLS, B. The Voice of Documentary. In NICHOLS, B., ed., Movies and Methods: An Anthology, vol. II, pp. 258–273. Berkeley: University of California Press, 1985.

PERSSON, D., GARTNER, G., and BUCHROITHNER, M. Towards a Typology of Interactivity Functions for Visual Map Exploration. In STEFANAKIS et al. (2006), chap. 15, pp. 275–292.

PETERSON, M. P. Interactive and Animated Cartography. Englewood Cliffs, N.J.: Prentice Hall, 1995.

———. Between Reality and Abstraction: Applications of Cartographic Animation, 1996. Available: http://maps.unomaha.edu/AnimArt/article.html. Accessed: Nov. 26, 2007.

———. Active Legends for Interactive Cartographic Animation. International Journal of Geographical Information Science, vol. 13, no. 4, pp. 375–383, 1999.

———. The Internet and Multimedia Cartography. In CARTWRIGHT et al. (2007), chap. 3, pp. 35–50.

PETERSON, M. P., ed. Maps and the Internet. Oxford: Elsevier Science, 2003.

———. International Perspectives on Maps and the Internet. Berlin; Heidelberg; New York: Springer, 2008.

RICE, M., JACOBSON, R. D., GOLLEDGE, R. G., and JONES, D. Design Considerations for Haptic and Auditory Map Interfaces. Cartography and Geographic Information Science, vol. 32, no. 4, pp. 381–391, October 2005.

ROBINSON, A. H. The Look of Maps. Madison: University of Wisconsin Press, 1952.

ROBINSON, A. H. and PETCHENIK, B. B. The Nature of Maps: Essays toward Understanding Maps and Mapping. Chicago; London: The University of Chicago Press, 1976.

RODAWAY, P. Sensuous Geographies: Body, Sense and Place. London: Routledge, 1994.

SÁNCHEZ, J., JORQUERA, L., MUÑOZ, E., and VALENZUELA, E. VirtualAurea: Perception Through Spatialized Sound. In Proceedings of the 4th International Conference on Disability, Virtual Reality and Associated Technologies, pp. 197–204. Veszprém, Hungary: ICDVRAT/University of Reading, September 18–20 2002.

SERVIGNE, S., LAURINI, R., KANG, M.-A., and LI, K. J. First Specifications of an Information System for Urban Soundscape. In IEEE International Conference on Multimedia Computing and Systems (ICMCS'99), vol. II, pp. 262–266. 1999.

SIEKIERSKA, E., LABELLE, R., BRUNET, L., MCCURDY, B., PULSIFER, P., RIEGER, M. K., and O'NEIL, L. Enhancing Spatial Learning and Mobility Training of Visually Impaired People: A Technical paper on the Internet-based Tactile and Audio-tactile Mapping. The Canadian Geographer, vol. 47, no. 4, pp. 480–493, 2003.

STEFANAKIS, E., PETERSON, M. P., ARMENAKIS, C., and DELIS, V., eds. Geographic Hypermedia: Concepts and Systems. Berlin; Heidelberg: Springer, 2006.

TAYLOR, B. Mapping your way: First announcement of google maps. World Wide Web Log (Blog) published by Google Inc. at http://googleblog.blogspot.com/2005/02/mapping-your-way.html, 2005a. Accessed April 18, 2008.

TAYLOR, D. R. F. Cartographic Communication on Computer Screens: The Effects of Sequential Presentation of Map Information. In Proceedings of the 13th International Cartographic Conference, vol. I, pp. 593–611. Morelia, Michoacán Mexico: International Cartographic Association, October 12–21 1987.

———. The Concept of Cybercartography. In PETERSON (2003), chap. 26, pp. 405–420.

———. The Theory and Practice of Cybercartography: An Introduction. In TAYLOR (2005b), chap. 1, pp. 1–13.

TAYLOR, D. R. F., ed. Cybercartography: Theory and Practice. Amsterdam: Elsevier Science, 2005b.

THÉBERGE, P. Sound Maps: Music and Sound in Cybercartography. In TAYLOR (2005b), chap. 17, pp. 389–410.

THIRION, S. Cascade on Wheels. Trans Parent Web Design (http://www.trsp.net/cow/), 2007.

THROWER, N. J. W. Animated Cartography. The Professional Geographer, vol. 11, no. 6, pp. 9–12, 1959.

TVERSKY, B., MORRISON, J. B., and BETRANCOURT, M. Animation: Can it Facilitate? International Journal of Human-Computer Studies, vol. 57, pp. 247–262, 2002.

VETERE, F. and HOWARD, S. Prior Knowledge and Redundant Multimedia. 2000 IEEE International Conference on Multimedia and Expo 2000, vol. 2, pp. 605–608, 2000.