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Using sound to represent spatial data in ArcGIS ☆

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ABSTRACT

An extension to ESRI's, ArcGIS was created to allow spatial data to be represented using sound. A number of previous studies have used sound in combination with visual stimuli, but only a limited selection have looked at this with explicit reference to spatial data and none have created an extension for industry standard GIS software. The extension can sonify any raster data layer and represent this using piano notes. The user can choose from a number of different scales of piano notes and decide how the program plays the sound; this flexibility allows the extension to effectively represent a number of different types of data. The extension was evaluated in one-to-one semi-structured interviews with geographical information professionals, who explored aspects of a number of different data sets. Further research is needed to discover the best use of sound in a spatial data context, both in terms of which sounds to use and what data are most effectively represented using those sounds.

1. Introduction

There are many ways to show spatial data visually and extensive research has developed a significant number of novel methods for interactive visualisation techniques (e.g. Dykes et al., 2005), as shown within the field of geovisual analytics (Andrienko et al., 2007). Spatial data displays are increasingly complex and the visual capabilities of many users are being challenged (Turkey, 1990), sometimes to the degree where the visual sense is saturated and to represent more data another sense is required (Hughes, 1996). Sound has been suggested as a suitable tool for the presentation of information in addition to the traditional visual methods, but has received only limited attention in the literature.

This project presents a sonification tool, which enables the user to hear sounds associated with the magnitudes of unvisualised (and often unvisualisable) spatial information, which can then be assessed in conjunction with what is shown visually. Fisher (1994) was one of the first who implemented sonification with spatial data, using sound to represent uncertainty in land cover classification from a satellite image, where it would be problematic to show uncertainty visually. This work brings the concept up to date with modern, commercial GIS software (ArcGIS 9.2–10) and covers a broader range of examples including height (DEM) and a cartographic application showing displacement. The software is evaluated by a focus group ($n=15$) of geographic information professionals from Ordnance Survey.

The concept of sonification has developed significantly and has fundamentally changed over the past 20 years (Hermann, 2008) driven by both technological and conceptual developments. Sonification can be used in many different settings and contexts (Dubus and Bresin, 2011) and combining sonification with visualisation will be fundamental to understanding large and complex data sets in the future. The increasing amount of geoscience data will benefit from new and improved methods of representation including sonification.

This paper reviews the reasons for using sound to represent spatial data, and highlights previous attempts to provide sonification of spatial information. A new tool is presented and its effectiveness is shown by example data and evaluation by geographic information professionals.

2. Literature review

2.1. Sensory alternatives

It is not unusual for the visual sense to be saturated in a GIS environment, particularly when there is a large amount of data to display, or if the data has an element of uncertainty, which has traditionally been difficult to display effectively. There are a number of alternative ways of displaying uncertainty data, such as text labels, blurring, colour shading or desaturating (Appleton et al., 2004) but visual methods risk conflicting with the display of

☆ Code available from server at http://www.nickbearman.me.uk/go/bearman_fisher_2011.

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the underlying information. While sonification is not limited to uncertainty, it is a frequent example because generally the uncertainty data covers the same spatial area as the underlying data (e.g. if the underlying data is temperature, the uncertainty could be range in temperature) and many of the visual methods to represent the uncertainty would obscure the underlying data. A further reason to use sound is to reaffirm information shown visually, which has been shown to provide greater understanding by the user than when data was just shown visually (Bearman and Lovett, 2010).

With modern computers it is possible to use other human senses to communicate information. Taste and smell are very difficult to control technically, both from hardware and specificity points of view, but the use of smell has been attempted (Brewster et al., 2006). However it would be quite difficult for these senses to be quantified and used to show ordinal data. Work has been done using touch (haptic) interfaces, but these require specialised hardware, which can be expensive to purchase (Jacobson et al., 2002). Sound is an easily accessible alternative, as the hardware is readily available and people are familiar with listening to sound in many different situations. Sound is also considered the most powerful sense in the body after vision (Fortin et al., 2007) and is technically the easiest to achieve. Sound, however, is still novel to geoinformation users and training may be necessary (Pauletto and Hunt, 2009).

Of the significant range of examples using sonification, very few have made use of sonification with spatial data. Much of that research is now relatively dated because of the very rapid progression of available technology over the last 20 years. However, these initial forays into sonification of spatial data are still relevant and represent a starting point to this work.

Krygier (1994) reviews the use of sound to represent spatial data and highlights 9 different aspects of sound that could be altered, including location, loudness, pitch, register, timbre, duration, rate of change, order and attack/decay. There are limits on how these different aspects can be combined, but conveying one set of data (or metadata) is certainly possible, and some tests have worked with multiple sound variables for exploration of multivariate data (e.g. Flowers et al., 1996). The work in this paper uses a single sound variable, to reduce the complexity of the task for users.

Gaver (1989) highlights the fact that sound is a transient phenomenon (whereas vision is generally a static phenomenon) and this must be taken into account whenever sound is used. This implies that sound cannot be used as a simple substitution for vision, as it is unable to communicate an overall impression or pattern of the data. However, if used correctly it could be used to represent a large amount of information over a small spatial area.

Together, the work by Krygier and Gaver gives an overview of the use of sound from a theoretical point of view. A number of prototypes based on these principles have been created in various disciplines; the next section reviews their implementation and, where completed, user testing.

2.2. Previous examples using sound to represent spatial data

One of the most common applications of sound with spatial data is for maps or navigational aids for people with visual impairments. Zhao et al. (2008) developed 'iSonic', which is a geographical data exploration tool for the blind, splitting the map data shown on screen into a 3×3 matrix, which is then sonified and accessed by the user pressing numbers 1 to 9 on the numeric keypad. Miele et al. (2006) created an example using a combination of sound and tactile interface, with the overall spatial data (e.g. streets, buildings) shown using tactile devices, and associated information (e.g. street names) read out on demand. Users could also add their own recordings as 'audio tags' at specific locations on the map. While these examples are for blind users and therefore not directly related to this study, they are an example of the methods used to represent spatial data sonically.

Sound can also be used to augment the visual senses, and arguably this is where it can be significantly more powerful than either vision or sound alone. Fisher (1994) and Veregin et al. (1993) developed different methods of using sound with spatial data when GIS technology was at a relatively early stage. Fisher used the example of uncertainty of classified images for the sound and Veregin used the example of soil map quality. They were both motivated by the desire to show data quality information in a way that would not obscure the underlying data, with sound being the option they chose to use. Lodha et al. (1996, 1997) created what they termed a 'sonification toolkit', which was designed to allow users to sonify geographic data. The users could choose how to relate different aspects of sound (e.g. tempo, volume or pitch) to geographic variables, which were triggered as the mouse moved over them. They did not develop the toolkit with a specific application in mind, but singled out uncertainty (within data) as something that would benefit from this technique. These examples were early implementations of sonification and were limited by the technology available at the time. As computer technology developed, so did the scope and potential of sonification.

Gluck (2000) used sound as a way to show different levels of environmental risk in counties in New York. He experimented with a number of different ways of sonifying the same data, including the use of ranges of sound, multiple notes and chords. They concluded that using sound and vision in conjunction with each other worked particularly well, giving greater information and understanding than either would separately. However this was only a pilot study with a small number of evaluators. Jeong and Gluck (2003) completed a set of user testing ($n=51$) comparing haptic, sonic and combined display methods in terms of usability. Participants reported that they preferred the combined (haptic and sound) method, although the evaluation showed that this was less effective than haptic alone. The sound methodology altered volume, which may have limited the effectiveness of sound in this situation because of the limited variations available. MacVeigh and Jacobson (2007) created a similar example to assess the technique's utility in displaying multivariate information in complex information displays, this time using different land use types (sea, land and harbour) and they concluded that it was a very useful concept, but did not evaluate this with any users.

Of the above examples, only Jeong & Gluck carried out any significant user testing to evaluate the effectiveness of using sound for their stated purpose. This may have been because the stand alone nature of the product made it difficult to roll it out to large numbers of computers (for evaluation) or limited time and resources. MacVeigh and Jacobson suggest that sound capabilities could be created as an extension to commercial GIS software, which would allow easier use, testing and evaluation of this technique.

3. Methodology

3.1. The sonification tool

The extension was written as an ArcObject in VBA (Visual Basic for Applications) and is an independent piece of code compatible with ArcGIS versions 9.2–10 (ESRI, 2011). This software was chosen because it is an industry standard product, with a freely available piece of code used to provide sound interaction

(Oliveira, 2008) using the MIDI interface. The program was designed to be simple to use for geographic information professionals and sufficiently adaptable to allow the user to choose different types of sound for use with different data sets.

The program was implemented via a custom toolbar in ArcGIS. When the tool is in use, the pointer triggers sound (musical notes) based on the data at its current location. Only raster data sets can be interpreted in this version of the program, but the concept could easily be extended to vector data sets.

There are three options for the user (Fig. 1): the layer to be sonified, the musical scale to use, and the sound playing option to use. The first option allows the user to choose any of the raster data layers within the current project (and which band within that layer) to be sonified.

The second option allows the user to choose the musical scale. The notes used are standard white piano notes, taken from the range of white notes (i.e. natural notes, not sharps/flats) on a piano. There are five different musical scales available, with the number of notes varying from 8 to 50. The scales use a particular set of notes (such as C, E & G), which is then repeated across a number of octaves. The available scales are listed in Table 1.

The scales available were chosen based on music theory—for example the notes C, E & G form a major triad and so sound harmonious together (Burrus, 2009). The Pentatonic scale is also a standard musical scale and C Major is all the natural notes available. C Octave was included to see if participants could differentiate between the same note in different octaves. Once the scale is chosen, the values from the data set are stretched along the scale in an equal interval fashion, with the lowest value being the lowest note, and the highest value the highest note (Fig. 2).

The final option allows the user to choose how the sound is triggered: "Play on Click" means that the relevant note is played once when the user clicks the mouse; "Play when Mouse Stops" results in a note being played repeatedly when the mouse is stopped but not when the mouse is moving, and "Play while Mouse is Moving" causes notes to be played repeatedly while the mouse is moving over the data.

The data flow through the application is shown in Fig. 3 (below).

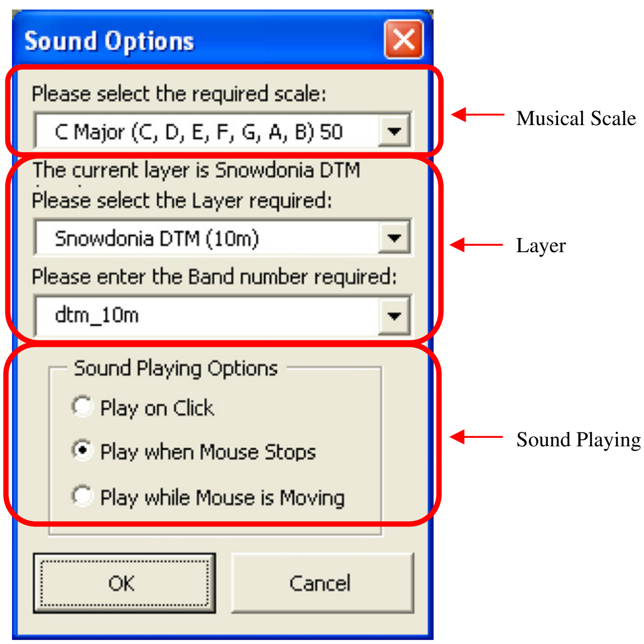

Fig. 1. Settings menu, accessed by right-clicking on the map with the tool selected.

Table 1
The different scales used, with the notes used and total number of notes.

Scale Name	Notes Used	Total Number of Notes
C Major	C, D, E, F, G, A, B	50
Pentatonic	C, D, E, G, A	36
Arpeggio	C, E, G	22
C & G	C, G	15
C Octave	C	8

3.2. Data

A number of data sets were used with the above tool to evaluate the use of sound to represent spatial data. This allows assessment of potential task specificity and wider applicability of the results.

3.2.1. Snowdonia aerial Photos and DEM

The first dataset used aerial photos of Snowdonia and the surrounding area from the imagery layer of MasterMap (Ordnance Survey, 2008a). A DEM (LandForm Profile, 10 m resolution) of the same area (EDINA, 2008) was also obtained but was not visible to users, being sonified instead: lower- and

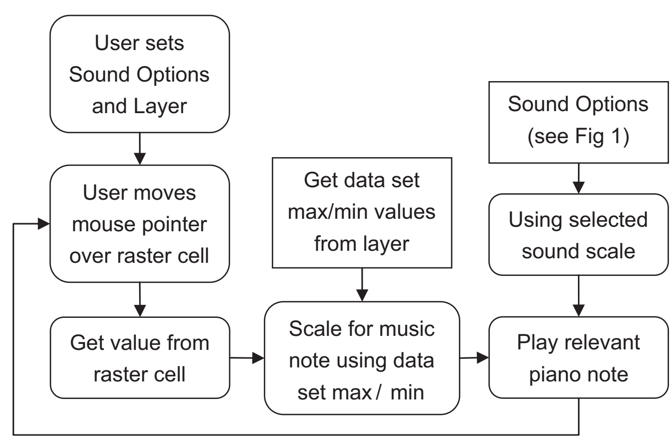

Fig. 3. Flow chart showing data flow through the application, specifically the process to play a sound from the current raster cell. The loop is repeated each time the user moves the mouse, and a new sound is played if the mouse moves to a different raster cell.

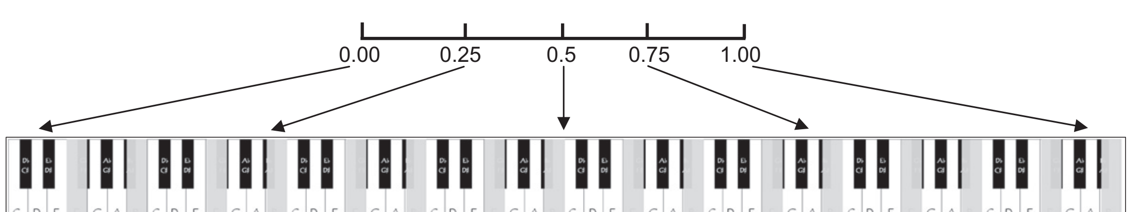

Fig. 2. Diagram showing data values mapped onto the pentatonic scale. Grey keys are not used in the scale.

higher-pitched piano notes were used to represent lower and higher elevations, respectively. Users could then, for example, trace the path up to the summit of Snowdon, and hear the notes increase in pitch until the summit is reached (see Fig. 4 and video at http://vimeo.com/22290359 or http://www.nickbearman.me.uk/go/bearman_fisher_2011).

3.2.2. Cornwall classification uncertainty

The term 'uncertainty' has many different meanings in relation to spatial data (Zhang and Goodchild, 2002); for this paper the term refers to measurement based error i.e. how different an object is from its value in real life. The example used is classification from remote sensing, and the uncertainty is referring to whether the pixel is correctly classified (Fisher, 1994). This type of uncertainty has often been ignored by common GIS solutions (Unwin, 1995), but is beginning to be addressed. An example of this is the UK Climate Projections 2009 dataset, whose projections are provided with probabilistic information, which must be represented and understood in order to effectively use the data (Jenkins et al., 2009). This is also becoming more relevant with the requirements of uncertainty within metadata from the EU INSPIRE project (INSPIRE, 2011; Comber et al., 2006).

In this work a Landsat ETM+ satellite image from 24/07/1999 (USGS, 2008) of Cornwall was used, with sound representing the uncertainty of the classification of each pixel. This was classified with a Maximum Likelihood Classification (MLC) from the BAYCLASS function in IDRISI Andes (Clark Labs, 2008). The MLC was used to represent the level of uncertainty of the classification on a pixel by pixel basis, with values from 0 (low uncertainty) to 1 (high uncertainty) (Fig. 5).

3.2.3. Displacement

The most abstract data evaluated shows object displacement as a result of cartographic generalisation. To allow display at different scales, particularly very small scales (e.g. 1:1,000,000), spatial features may be moved from their true location to avoid conflict with others on the map, or enlarged to ensure that the more important features are clearly visible. Fig. 6 shows Shirley Warren, Southampton; the road is from the ITN Layer and

Fig. 4. Snowdonia Aerial Photograph and DEM example in ArcMap. The white areas in the DTM represent flat areas and are errors from the data conversion. The line shows one of the routes up Snowdon, and this was traced using the mouse to show how elevation changed from the base to the peak.
Source: Ordnance Survey. © Crown Copyright. All rights reserved

buildings from the topography layer of Ordnance Survey MasterMap® (Ordnance Survey, 2008b).

The building displacement was calculated using Radius Clarity (1Spatial, 2008) and the vector displacement data was converted into raster format, to allow the data to work with the extension. Fig. 6 shows the displacement (in blue), which was sonified, with a higher note representing a higher level of displacement.

4. Evaluation

Geographic information professionals ($n=15$) from the Ordnance Survey formed a focus group to evaluate the software. All the participants used GIS regularly, and understood the issues surrounding the use of spatial data and the potential effects of uncertainty. On a one-to-one semi-structured interview basis, their background and experience was recorded, as well as their views on the tool. They were given a demonstration of the tool, allowed to use it freely and then asked for their feedback and suggestions for future improvements. The technique of semi-structured interviews was chosen for this evaluation because it allowed participants to explore the software in a relaxed manner without the need to follow a pre-set structure. It also allowed for discussion with the participants about which aspects they liked, did not like or needed further explanation of. The technique of sonification was very new to the participants so the semi-structured method allowed them to explore the sonification tool without needing to have an in-depth knowledge of the terminology to communicate their feedback (Barriball and While, 1994).

Participants adapted to the sonification quickly, and the majority of them reported that the sound added something to the data exploration experience. While the specifics of the sounds used could be improved, as explored below, the principle appears to hold a significant amount of promise.

The method used to play the piano notes was felt to be too repetitive; participants preferred that the sound changed smoothly from one note to the next, rather than being resounded every 10 ms. A different instrument that had more sustained notes would have helped, such as an organ or brass instrument. The C Major scale, consisting of the natural piano notes (white keys, $n=50$) was felt to utilize too many notes; one participant described it as sounding 'a bit scary' and having 'bum notes', by which they meant the notes were discordant. Scales with fewer notes were preferred, and the Arpeggio and Pentatonic scales were seen as best because they sounded more harmonious; they are often used in music for this reason.

While there was a general trend for preferred combinations of data and interaction methods, this did vary between participants. It was suggested that harmonious or dissonant chords could be used instead of the single note scales provided in the program. Therefore a harmonious chord would represent high accuracy and a dissonant chord low accuracy. More research would be required to establish whether a level of musical experience is required for this to be understood. Another suggestion was to use different instruments, to allow more than one variable to be represented at once. Such suggestions, while interesting, have great potential to make the tool too complex—something which should be avoided as the user is already dealing with a relatively unfamiliar interaction method.

Participants generally found it easy to compare the relative difference between sonified values; one participant specifically noted that the direction of the scale (i.e. low notes = low accuracy) was intuitive and therefore the sounds made logical sense. However, it was difficult to associate them with an absolute value (i.e. is that value 0.6 or 0.7; is that cell's uncertainty twice as high as this cell's?). Whilst this obviously depends on the data set

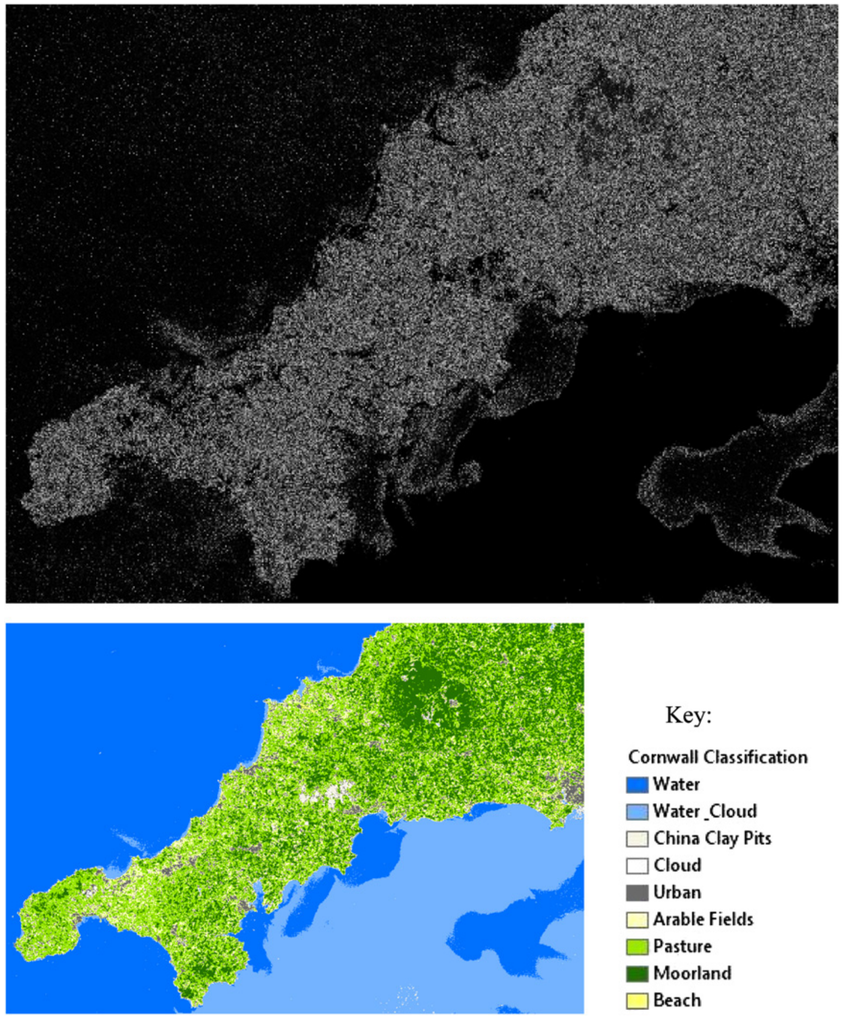

Fig. 5. Classified Landsat image (above) and the uncertainty information (below). Black represents a value of 0 (no uncertainty) and white represents a value of 1 (maximum amount of uncertainty).

Fig. 6. Generalisation example with the original location of the buildings shown in a grey outline, the new location shown in orange (left and above), and the displacement shown in blue (below, this would be sonified). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.) *Source:* Ordnance Survey. © Crown Copyright. All rights reserved

involved, some orientation of the value within the dataset would assist. This could be done by showing a histogram of the data with the currently-selected value highlighted. For spatially large data sets, it was suggested that an average value could be useful, which would allow the user to decide whether they needed to zoom in for more detail. This could take the form of a resizable, movable polygon (similar to a focal operation in raster processing), which summarizes and presents the data to the user sonically. It was suggested that peoples' abilities to utilize the sonification effectively would improve with their previous knowledge of the data set and with experience of using the tool. These aspects could not be investigated in the time available but would be appropriate for future research.

The examples of data provided have different complexity levels and the simpler ones were easier for the participants to understand than the more complex ones. It was common for particular interaction methods (such as ''Play while Mouse is Moving'') to work most effectively with different examples (such as Snowdonia Aerial Photos and DEM). Data that was continuous (such as height, where there is likely to be a gradual progression from cell to cell) worked well with ''Play while Mouse is Moving'', which provides a large amount of information to the user through the sonic channel, whereas data from the Cornwall Classification Uncertainty example was discrete and adjacent cells are not necessarily similar in value. Therefore ''Play on Click'' is a more effective method, as this provides the user with the information at a slower and more controllable rate.

Overall a significant amount of data was collecting from the semi-structured interviews. Of particular note is that the majority of participants preferred the Arpeggio and Pentatonic scales because of their harmonious nature. Additionally, the preference for particular interaction methods to be used with particular data sets highlights the need to create an appropriate interface for the sonification—it could even be said that this is of equal importance to the sounds used for the sonification.

5. Conclusion

This study has evaluated the use of sound to represent spatial data, using piano notes and data examples within ArcGIS. Sound has been utilised in similar ways before, but with a general lack of both user evaluation and integration with an industry standard GIS. Both are required for this technique to be used more widely (MacVeigh and Jacobson, 2007).

The focus group results suggest that continuous data sets (such as Snowdonia Aerial Photos and DEM) could be sonified and understood more easily than discrete ones because of the lower variability of the data. However, at a general level all of the participants easily understood the link between note pitch and data value, and felt they could use information conveyed by sonification. Participants suggested a number of improvements to make the sonification easier to use and understand, including variations to the sounds used in terms of voice, harmony and duration; varying responses to the three example data sets highlighted that different solutions may be appropriate for different purposes. In particular, reactions to the ''Play when Mouse Stops'' and ''Play while Mouse is Moving'' methods strongly suggested that they lend themselves to different types of data.

More research on applying aspects of musical theory in a spatial data context is required to help with choosing, which sounds to use and understanding how users interpret the sounds they hear in terms of spatial data. This has been considered in the music literature (Neuhoff et al., 2002; Rusconi et al., 2006), but only in a limited way, and there has been little GIS research directly addressing the interaction between different types of sound and spatial data.

The use of sound to represent spatial data is not a new topic, but little has been done in terms of evaluating its use and understanding the science behind the interpretation of sound in this situation. This work demonstrates that there is potential in the technique and that there are preferences for specific musical scales, but also highlights that further research and testing is needed if usable and effective tools are to be developed.

5.1. Web resources

Example videos of the sonification techniques, source code and other relevant information are available from http://www.nickbearman.me.uk/go/bearman_fisher_2011. Additionally, these are further duplicated at:

- Vimeo—video demonstrations of the sonification techniques
  - http://vimeo.com/22290359
  - http://vimeo.com/22290435
- ShareGeo—source code
  - https://www.sharegeo.ac.uk/handle/10672/204 (or http://hdl.handle.net/10672/204)

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