AGILE: GIScience Series, 3, 35, 2022. https://doi.org/10.5194/agile-giss-3-35-2022
Proceedings of the 25th AGILE Conference on Geographic Information Science, 2022.
Editors: E. Parseliunas, A. Mansourian, P. Partsinevelos, and J. Suziedelyte-Visockiene.
This contribution underwent peer review based on a full paper submission.

Sonification of Spatial Data: An Online Audiovisual Cartographic Representation of Fire Incidents

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Abstract. The possibilities of using sound in cartography have been formulated by numerous researchers. However, there are still no general guidelines for mapping data dimensions to auditory variables, while the decision of which spatial data dimension to represent by which sound variable is crucial. The method for embedding sound in maps is commonly known as "sonification"; the representation of data through sound. Many researchers use sonification to convey their data through the auditory channel as an alternative way to understand and represent our complicated world. With this in mind, we created an interactive web map that depicts the fire dynamics, adopting the sonification technique of parameter mapping; a sound variable was used to represent fire duration. For assessing the effectiveness of different sound variables for this map, an online survey was conducted. The main finding is that to represent spatial data through sound, participatory approaches can highlight the most effective cross-modal correspondence.

Keywords. sonification, sound variables, audiovisual map, wildfires, Mapbox

1 Introduction

Understanding sound is a complex process. Each sound is unique and possesses special characteristics that make it distinguishable (Seashore, 1967). Sound individuality helps cartographers convey information on maps in a different and innovative way. In combination with visualization, sonification is an effective form of data representation as it has complementary properties which can enhance users' perception and understanding of spatial data.

2 Related Work

Researchers are motivated to incorporate sound into their cartographic products for various reasons. For example, sound's ability to efficiently map changes in data over time supports the development of animated maps, and its ability to manage large amount of data imposes no relevant limitations (Hermann et al., 2011). Moreover, unlike vision, sound exists over space meaning that users do not have to come into direct contact with the auditory source (Houben, 2002). Also, as an alternative to traditional visualizations, cartographic auditory displays make data accessible for visually impaired users providing them a multimodal, multisensory and more effective experience (Josselin et al., 2016, Nees and Walker, 2009, Kramer et al., 1999, Kramer, 1994).

The term "multimodal interfaces" often refers to interfaces that process multiple user input modes (Furht, 2008), while the term "multi-sensory interfaces" refers to those that represent data in multiple sensory channels. Multimodal, multi-sensory interfaces combine these two functions. The human brain can use multiple sensory channels simultaneously to gather the necessary data to clarify incomplete or misleading data provided by a single sense. It is also known that the use of audio feedback can increase functionality while reducing visual overload.

Sonification is defined as the process of using nonspeech audio to convey information (Kramer et al., 2010), it is interdisciplinary and it has been utilized in a variety of applications. Several scientific fields such as cognitive science, computer science, product design, acoustics, and audio engineering have been researching sonification for decades.

There are various sonification techniques such as audification, parameter mapping sonification, model-based sonification, earcons and auditory icons (Hermann et al., 2011). Audification is the process of directly translating data into sounds and is applicable only to structured data sources such as time. Specifically, audification involves shifting the waveforms of periodic data into the audible range of frequencies for data exploration (e.g., seismic data) (Nees and Walker, 2009). Parameter mapping sonification involves the association of information to auditory parameters for the purpose of data representation and is particularly well-suited for displaying multivariate data. Earcons are short, structured audible cues that serve as an index to abstract messages. Auditory icons have an existing relationship between the sound and the information that it provides (Hermann et al., 2011).

An effective sonification requires careful consideration of the types of users, tasks, and environments where the method will be implemented. Before applying sonification to data, designers must decide on the suitability of the available techniques. Another challenge in designing an auditory display is the lack of evidence-based guidelines. Moreover, the users' memory capacity is an essential part of their auditory perception and its limitations should not be overlooked. Like visualisation, sonification can also be limited by memory's temporal constraints (Kramer et al., 2010), especially when dealing with continuous or dense datasets.

Thus, the most important decision to be made is the right choice of sound variable. Krygier (2008) has introduced a taxonomy of sound variables that can be used to convert data into sound. Krygier's sound variables are location, pitch, loudness, duration, register, timbre, rate of change, order, attack/decay. Pitch is the most used variable according to the study by Dubus and Bresin (2013), and we can assume that this is due to human's pitch discrimination mechanism. Each variable is suitable for a specific data type (ordinal/ nominal), and an arbitrary selection would compromise the final sonification product. Furthermore, the data dimension that is going to be represented (e.g., size) plays a significant role in the choice of sound variable. There is little empirical evidence in cartography investigating the optimal correspondence between what is represented and the sound variable. Walker and Kramer's (2005) experimental study shows that temperature is best displayed with pitch, and size with loudness.

The lack of empirical evidence also complicates the decision regarding the appropriate correspondence between the sound variable and the value of the represented attribute. For example, Krygier (2008) and Nath (2020) argue that pitch should become higher as the value of the represented data increases (high pitch - high value), but cognitive science empirical results favour the opposite (Evans and Treisman, 2010). Hence, it becomes difficult to estimate which correspondence directionality produces better results. To find out which one is more effective we need to perform user studies.

3 Audiovisual map design process

The developed online interactive map depicts the occurrence of large-scale and intense fires worldwide. Warmer weather conditions in recent years have lengthened the duration of the seasons in which fires occur worldwide (Jolly et al., 2015). Recent studies have shown that ongoing climate warming and drying contribute to the occurrence of large-scale and intense fires (Hantson et al., 2017).

3.1 Fire data

The fire data are derived from the Global Fire Atlas (Andela et al., 2018), a freely available dataset that tracks the daily dynamics of individual fires and provides data about the time and location of ignition, fire size, duration, daily expansion, fire line length, speed, and direction of spread. The data are generated from the MODIS Collection 6 burned-area dataset (Giglio et al., 2018). The data refer to the period from 2003 to 2016 during which, the algorithm identified approximately 13.3 million individual fires worldwide.

3.2 Data Representation

Forest fires are a phenomenon in which several factors of varying severity come into play. Meteorological, topographical, and vegetation factors mostly influence the outbreak and spread of fires. The complexity of the phenomenon makes it ideal for auditory display.

Since the amount of data was very large, we explored the bibliography for a suitable fire categorization scheme. Preference was given to a classification scheme based on the burned area size. However, our investigation revealed that such a scheme does not exist. Hence, a portion of the data was selected for representation to avoid visual and auditory overload of the user. After a series of tests, the threshold of 100 km^2 for the extent of the burned area was chosen so that the data would suffice to illustrate the complexity of the phenomenon, but also to facilitate the reading of the map. The map represents three attributes: burned area size, fire duration and speed of spread.

The attributes are represented using proportional point symbols. Circles were selected due to their compactness, visual stability, and effectiveness in representing a second variable (Dent et al., 2009). The size of the circles is proportional to the size of the burned areas. Changes in colour hue and value were used to represent the speed of spread, while the fire duration was represented through sonification and the method used is parameter mapping sonification (PMSon).

3.3 Audio embedding

The last step was the integration of sound into the map. At this point, a meaningful question emerged: Which sound variable should be used to represent fire duration? To select the appropriate sound variable, a survey was conducted using Alchemer online platform. Results from this survey guided the final selection of the sound variable adopting a participatory-based design approach. The three sound variables studied were: duration, pitch, and loudness.

Audacity software was used to create the audio files included in the survey. Three sets of audio files were created; one for each sound variable. The set for the duration variable included four individual files of distinct durations; 0.1, 0.3, 0.6, and 1 sec. The audio files for the pitch variable had sequential frequency variation of 30Hz, starting from 250Hz upwards. The audio files for the loudness variable differed successively by 8dB.

3.4 Survey outline and results

Due to Covid-19 restrictions, the study was performed remotely; thus, the respondents answered the questions through their personal computers. For some questions the users' reaction time was also reported.

The questionnaire included 31 questions divided in four parts:

- Part 1 includes the demographics questions,
- Part 2 has 6 introductory questions giving insights into how participants perceive and interpret sound variables,
- Part 3 consists of 12 questions that users had to answer while exploring three versions of a sample map; each for one of the sound variables tested, and
- Part 4 includes 6 overall assessment questions.

The questionnaire was answered by 64 participants (24 females). Participants did not differ much in age, as 86% of the sample was younger than 36 years old. In general, users correctly understood the qualitative differences of each variable, however, showing wide variance in perceiving differentiations in pitch. As for the reaction time, it can be observed that pitch needs more time to be understood than the other two variables (Part 2).

Results regarding map exploration (Part 3) indicate that users may not easily correspond pitch to the represented data. Although many participants (78.31%) indicated that sharp tones (high pitch) must correspond to higher values of the phenomenon presented (fire duration), the low percentage of correct answers (53.12%) to questions corresponding pitch to fire duration indicates that users might not understand the conveying message. As for the time response, the longer response time indicates that users spent more time listening to the different pitch sounds until they were able to answer the questions, than they did for the other sound variables.

The main conclusion drawn from the responses is that the sound variable of duration seems the most appropriate to represent the duration of a fire event. The percentage of participants who selected this variable was 51.6%, while pitch was selected by 15.6% and loudness by 31.3% (Part 4). Thus, it was decided to use the sound variable of duration for the auditory representation of fire duration. The conceptual relationship between the attribute being presented (fire duration) and the sound variable of duration may have influenced users in their final choice.

3.4 Data and Software Availability

The used dataset can be found at http://www.globalfiredata.org/fireatlas.html.

To implement the "Audiovisual Fire Map" several tools have been used, such as GIS software packages and tools, programming languages, and web libraries. The JavaScript programming language was used along with HTML5 and CSS3. Data management and analysis was performed on ArcGIS Desktop. Finally, the map was created and published using Mapbox platform.

Questionnaires were collected anonymously. An Exemplary Questionnaire in English, the links to the sample maps used, the auditory datasets used, and all necessary metadata supporting this publication, are available on figshare and are accessible via the following DOI: https://doi.org/10.6084/m9.figshare.19626357.v3.

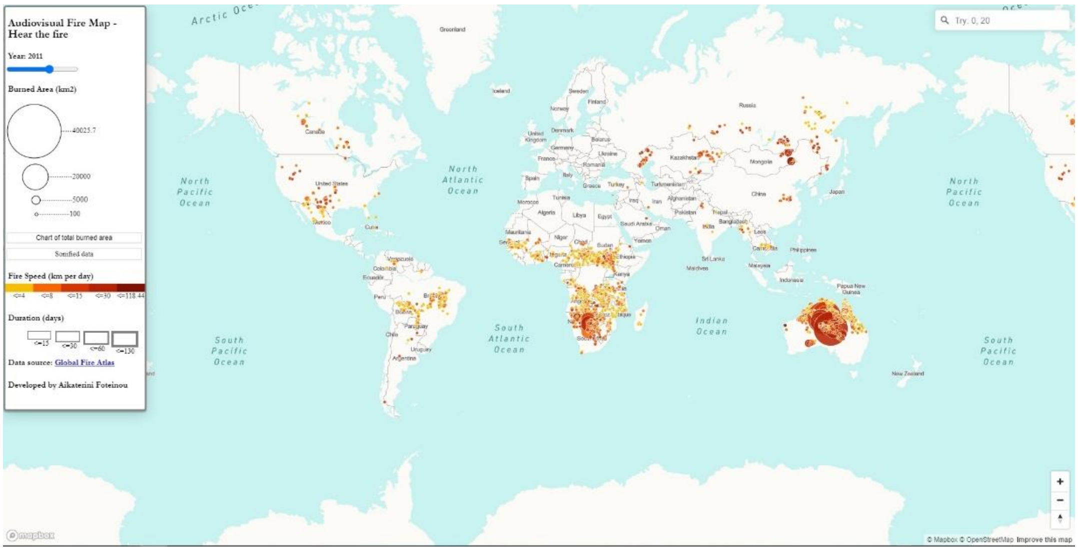

Figure 1: Interface of Audiovisual Fire Map (http://cybercarto.ntua.gr/AudiovisualFireMap/AudiovisualFireMap.html)

3.5 The "Audiovisual Fire Map"

The developed cartographic product is an interactive audiovisual interface that uses two channels to convey spatial information; the visual and the auditory. The interface is divided into two parts. The dominant element of the screen is the cartographic representation, while a control menu (console) is available on the left side of the screen (Fig. 1). When a user visits the application, she encounters a pop-up window with information about the map content. The map legend refers to the three represented fire attributes; burned area, speed of spread, and fire duration.

The basic means of interaction is the computer mouse, which the user can utilize to explore the cartographic application.

The first interactive feature was the implementation of a time slider enabling the examination of the phenomenon through time. The second interactive feature is a pop-up window (Fig. 2) that appears when the user hovers the mouse over a point symbol, which provides additional information about the fire incident at that location.

The third interactive feature enables the user to enter geographic coordinates to a text window, to centre the map on that area of the world. Another interactive feature is the ability to centre the map when the user clicks on a symbol.

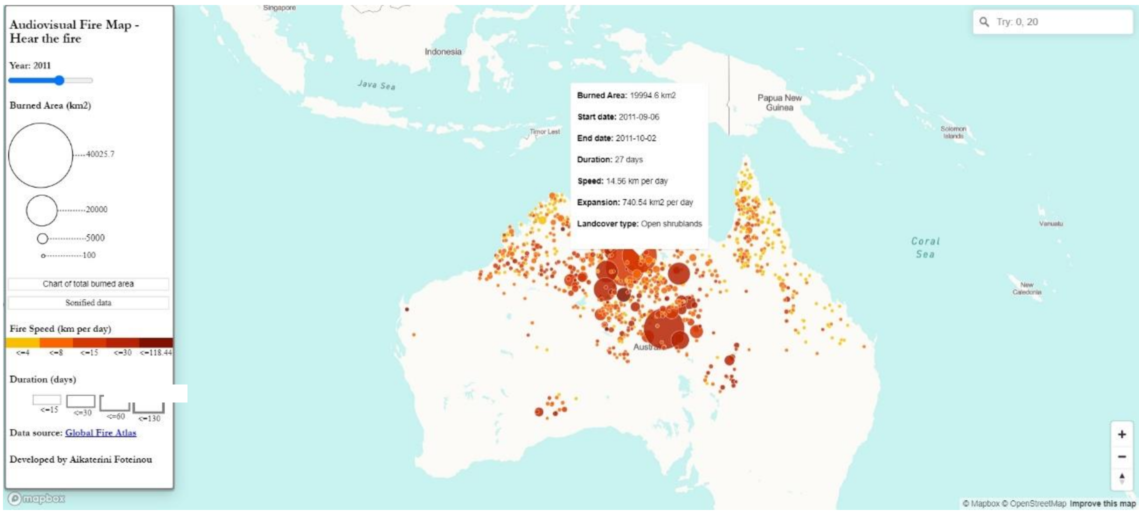

Figure 2: By hovering over a point symbol the user can hear the sonified fire duration. A pop-up window providing additional information about the fire incident also appears.

4. Conclusions

Although the visual sensory system is used extensively in human-computer interaction applications, the audio system is relatively neglected. However, some examples highlight its potential such the immersive exploration applications by Berger and Bill (2019) and the GIS-based audiovisual simulation for wind farm assessment (Manyoky et al, 20014). In particular, in the field of cartography, the attempts of Théberge, 2005; Schito and Fabrikant, 2018 have addressed the proper application and incorporation of sonification into the map production process.

The Audiovisual Fire Map gave us the possibility to combine both the visual and auditory channels to convey information on a complex spatial phenomenon represented by three variables. The empirical study highlighted interesting results regarding the participants' perception of auditory variables and demonstrated the ability of these variables to support multivariate mapping. Especially, the use of pitch seemed to result in higher variability and uncertainty regarding the representation of quantitative data which conforms to the ambiguity in existing empirical evidence. This highlights the need for further research to determine the perceptual correspondence between spatial data variables and auditory ones. We are obliged also to consider limitations of the current study since it was performed remotely, prohibiting participants from using the same hardware.

Acknowledgments

The research work was partially supported by the Hellenic Foundation for Research and Innovation (H.F.R.I.) under the "First Call for H.F.R.I. Research Projects to support Faculty members and Researchers and the procurement of high-cost research equipment grant" (ProjectNumber: HFRI-FM17-2661).

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