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Abstract

In this article, we test the usability of a cartographic tool mixing maps and sounds. This tool is developed within QuantumGIS as a plugin prototype. We first present some theoretical reflections about synesthesia. Secondly, we explain the way we «sonificate» the images, by associating colors and recorded chords and sounds. Then we present the results of several usability tests in France with different users, including blind people. We finally conclude on the contributions and the limitations of such a tool and draw some perspectives.

Keywords: sonorous cartography, image, colors, usability tests, blind people, soundscape.

1 Introduction

In this article, we present a prototype plugin for sonorous mapping and we test its usability mixing maps and sounds. We first explain how people perceive space in a single *esthesia* (use of a single sense) or *synesthesia* (combination of two neural senses). It concerns sighted and blind people as well, who developed different capabilities. Visual and auditory dimensions are compared and their relationship is discussed. In a second stage, we draw a concise state of the art about synesthesic cartography, which motivated our research.

Then we present the prototype plugin, which was developed within QuantumGIS. We detail the process to sonificate the images, by associating colors and different recorded sounds. Some examples of sonification illustrate the article content. We show the results of a usability test with different users, including sighted and blind people. We finally conclude on the contributions and the limitations of such a tool and draw some perspectives.

2 (Syn)esthesic mapping

### 2.1 Multi-sensory perception of space

Perception of space involves sensory processes, including vision and hearing, which are used to locate objects in space. According to Krantz [17], «senses are transducers from the physical world to the realm of the mind where we interpret the information, creating our perception of the world around us». Indeed, information received from all sensory processes can be grouped in several categories.

In contrast with *proprioception*, which gives information on the relative position of individual body parts and on their relation with surrounding space, these senses are all *exteroceptive*:

- Vision is the most powerful spatial sense; it provides direct access to information, extensive perceptual field, simultaneous apprehension of a very large portion of the near and outer space, processing speed, various and subtle object discrimination with a high spatial informational power; it plays a major role in initiating and controlling movements directed towards objects [12].
- Hearing is used for prospective manifestations of distance and position; it identifies the nature of objects less than the vision (not all objects emit sounds); hearing is also a spatial sense [12], because it allows a remote perception of moving sonorous objects and it codes information to a frequency field [16].
- Other senses are less effective for space apprehension. Touch, the perception of contact, is limited to a close perceptual field, even if it can be enlarged by scanning movements. Olfaction or smell is the sense that allows analysis of volatile «chemicals» in the air. It helps to detect a certain type of fragrant objects. Tasting is also a specific sense useless for mapping.

All these sensors may be combined in a synesthesic way for improving object detection. Moreover, results regarding needs of visually-impaired people to compensate visual perception, show that auditory and tactile information are the most appreciated senses [20, 8, 9]. For technical reasons and body maintenance, auditory may be the best
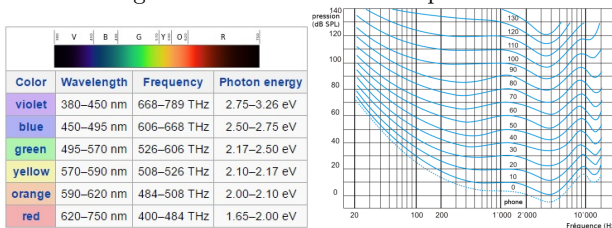
Figure 1: Newton wheel [3]
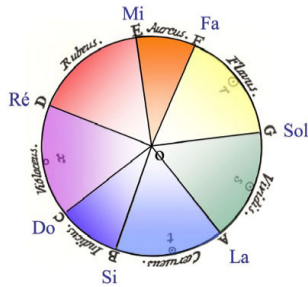
sense to comprehend an object. In our research, we only consider vision and hearing, more precisely how hearing may magnify visual or mental maps.

2.2 Visual *vs* auditory space

Correspondence between sound and color was largely studied over the centuries. Despite common characteristics in signal waves and physiology, it does not seem easy to directly match sounds to colors. The first reflections on the subject date back to Antiquity, with a classification from Aristotle in the 17th century. Then Marin Cureau de la Chambre (1596-1669) [3] compared color and music harmonies. Castel [7] paved the way for a series of reflections and positions on synesthesia, which is the combination of two neurological senses during a same experiment. Newton [21] had tried to design an analogy between colors and the seven notes of the diatonic scale as shown in the «color wheel» (cf. Figure 1). Can we establish a correspondence between sounds and colors rationally based on both characteristics of sound and light waves [3]? This bridge is difficult to build directly because there is no overlap between the frequency ranges of the sounds audible by the human ear (20 to 20 KHz) and the light visible by eyes (waves from 400 to 800 THz) (cf. Figure 2).

Figure 2: Color *vs* Sound frequencies

Color	Wavelength	Frequency	Photon energy
violet	380–450 nm	668–789 THz	2.75–3.26 eV
blue	450–495 nm	606–668 THz	2.50–2.75 eV
green	495–570 nm	526–606 THz	2.17–2.50 eV
yellow	570–590 nm	508–526 THz	2.10–2.17 eV
orange	590–620 nm	484–508 THz	2.00–2.10 eV
red	620–750 nm	400–484 THz	1.65–2.00 eV

Source: Wikipedia

2.3 Synesthesic cartography

Since the pioneering work of J. Bertin [4] in graphic semiotics, mapping has mainly evolved [11] on two aspects: interactivity [15] and online accessibility. For recent years, cartography included motion and time line [19, 14], *i.e.* animated, multimedia or interactive mapping [6]. However, most of the works done on semiotic is about data geovisualization. A few works dealt with sonorous maps semiotic [18, 11], but they concluded that joining images

and sound or music still needs major improvements, especially to associate memory capability and sounds.

On another hand, *«soundscape»* was developed in 1969 [25]. It uses the sounds of landscapes to give meaning to places and environment. For instance, a link between soundscape and GIS was proposed in [27]. Other authors mapped different sounds [26]. In this case, peculiar sounds characterize targeted places explicitly.

Directly in the lineage of the work from Newton and Castel, some authors developed applications to *«sonificate»* a map [2] and [24], by mapping elements of cartography (e.g. the color of figurative) and music components (e.g. notes, duration, chords).

Thus, cartography can be used in a synesthesic way [10, 13], but also be based on a single esthesia, especially when considering blind people, as proposed in this paper.

2.4 Space representation for sighted or blind people

Although is is very difficult to simulate blindness simply by closing eyes and due to the variety of pathology, we know that blind people are unable to build spatial patterns that require visual sense [23, 22]. However, these persons can feel natural proprioceptive patterns, and some kinds of exteroceptive schemes (touch, acoustic, olfactory), which help to locate in space. Studies showed that behavior of visually impaired and blind people changes from a person to another, several factors playing different roles. For instance, late blind people (in life) do not have the same difficulties in building space as people who recently became blind.

A question that often arises by specialists is the following: is it possible for blind people to acquire the same spatial knowledge (and at the same level) by implementing functions that compensate the lack of vision [12]? In fact, how knowledge is acquired does not really matter. It is a modeless or multimodal process that suggests there is no real difference between blind and sighted people cognition final functions due to adaptation [22, 12]. In many cases, mental structure of blind people may be different and space perception can refer to a touch or sound idea [12].

Somehow, visually impaired people have another definition of space:

$Distance = Time$ and $Environment = Touch + Sound$

This implies that $Space = Time + Touch + Sound$, which is the assumption we state in this article.

Compensation of visual impairment of blind people by the auditory sensory field is a technique that wows scientists. Several studies brought interesting results in recent years. For instance, in 2012, Amir Amedi [1] and his team tested a new approach and devices to activate the visual cortex with text data coming from existing senses. Eight congenitally blind participants showed activation of the visual word area after 2 hours of training with listening soundscapes. Both sighted and blind individuals showed

activation of the same left ventral occipito-temporal cortex in response to letters.

In cartography, some experiments were proposed in [24] to join maps and music to comprehend geographical space in a synesthesic way. Developed within Quantum GIS, the tool allows to extract spatial patterns of pixels on images and to sonificate space areas using soundscape signatures and musical compositions which suggest representations of real territories.

On another hand, the use of spatial representations and calculations for musical structures is an active research field [5]. The question of the translation of a score map is somewhat similar to use a spatial structure extracted from a map with a set of musical constraints *(harmonic, melodic, rhythmic)*. We are then in a potentially fruitful approach linking sound, music and space.

The research we develop build on the idea that hearing sounds and music can be an efficient way to mentally represent space for both sighted or blind people. We developed a prototype that explores sound track mapping, exploiting images to emphasize the characteristics of the environment it represents (urban area, forest surroundings beside a river, etc.). It matches environmental characteristics and sound materials using a sonification process including soundscape. Other tests are proposed with music compositions associated to different land uses in the image. The software seeks to establish synesthetic correspondences with sounds evoking a more or less faithful representation of space.

3 Interaction between maps and sounds

We present here a plugin prototype developed within QuantumGIS.

3.1 Packages used in QuantumGIS

QGIS is a reference free Geographical Information System. Il allows to represent vector or raster data. Previously developed in C++, it proposes a Python interface. To sonificate sonorous sequences of ambient records or musical compositions, we used several packages (API):

- PyQt: to manage GUI interface (Graphical User Interface) ;
- Matplolib: to visualize data in the Matlab format;
- PyDub: for sound tracking and mixing;
- OpenCV: to visualize images;
- K-d Tree: to make easier to build and manage tree in k dimensions.

3.2 Image sonification process

Some techniques were already developed to match space and sounds by an automatic numerical translator that links color values (in the ranges from 0 to 255 for 8 bits images or from 0 and 65535 for 16 bits images) with interval [-1;1] by interpolation; see for example [2]. In such approaches, data are preserved (order, progression in values) but the sounds produced may be inaudible or at least spatially non significant.

The approach we propose is slightly different. We try to pass from sets of localized pixels made of three dimensions (color composed of three channels) to a recorded sound or a suggesting music supposed to represent this space without loss of sense. This is tested with sighted and blind users.

3.3 Algorithm to find the dominant color

QGIS can deal with raster images using 3 memory blocks assigned to each RGB color. We aimed at representing colors in a single value. To do so, we use the $Luminance - Chrominanc$ model that minimizes the distance between close colors. We chose the model CIELAB where L is the brightness, a is the position on an axis from red to green and b is the position on an axis from yellow to blue. This procedure requires to use OpenCV.

We first fix a series of discriminant colors that will be assigned to particular sounds or music sequence. On the image, we graphically choose a set of pixels in a window. Once this is done, we need to find the dominant (in our case the average) color in the set of pixels and to find out what is the corresponding color among predefined ones. To do this assignment, we use a kd-tree instead of Euclidian distance, which is more efficient and quicker.

3.4 Image and records

We propose two ways to sonificate the image: soundscapes and musical composition. Using PyDub, we apply a color matching, which allows to combine the dominant colors in an image from IGN (cf. Figure 3) with different types of sonorous sequences.

Five soundscapes are first used, corresponding to 5 dominant colors on the image. This list may be adapted to any images with different dominant colors. The sounds come from public libraries of soundscapes we wish to illustrate. Others were recorded in the neighborhood of Avignon, France. They are available online[1].

- Green refers to trees, grass and forest; the sound is a mixture of wind whistling on branches and steams and bird singing (hear the audio file $green0.mp3$ in the folder $Muse/Sounds/AS$);
- Blue describes rivers and in general, water; the corresponding soundscape is a water flow ($blue0.mp3$);
- Grey depicts industrial activities with buildings ($grey0.mp3$);
- Black denotes urban areas with houses, streets and kid shouts ($black0.mp3$);
- Orange suggests sounds emitted by vehicles on traveled roads ($orange0.mp3$).

A second approach consists in somehow developing a «musical speech» to evoke the colors and landscapes in the

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[1]https://drive.google.com/folderview?id=0BwczJf_wKm2_Tzc3MnVnYW15WE0&usp=sharing

Figure 3: An image to sonificate.

image. We propose two compositions, an acoustic melody and an electronic groove (rhythm). We also have 5 different patterns corresponding to each color. Some are proposed by authors of this paper and others were composed by other music composers for the usability test. They can be respectively downloaded in both folders $/Sounds/OB$ (acoustic) and $/Sounds/DJ$ (electronic).

3.5 Composing the sounds according to the colors distribution

The key variable is the volume. It is indeed proportional to the frequency of pixels of a certain color (after assignment) in the window. When a color is dominant on the image, then the soundscape is the loudest. As the relation is not linear, we used the following formula in PyDub to process the gain of each soundscape:

$$Gain(c) = 20 \times \log(d/Dmax) \qquad (1)$$

with c a color among the five ones, d the frequency of corresponding pixels and $Dmax$ the maximum number of pixels belonging to one of the colors. This was used for both soundscapes and musical compositions.

4 Results and tests

4.1 Examples of sonorous sequences

Firstly, to test the prototype and its interface (Figure 4), we use a window of 100×100 pixels and we select a few typical locations to be sonificated as examples, which can be downloaded online in the folder $Muse/Compo$:

- A first location identifies a crossroad downtown, with a neighborhood made of kid shouts and car noise (cf. Figure 4); sounds and music depict an urban area, sometimes represented by a hectic sonorous sequence pulsated by marked rhythms; see the corresponding soundscape in sub-folder $/Compo/AS2/AS0.mp3$, acoustic melody in $/Compo/OB2/OB0.mp3$, electronic groove in $/Compo/DJ2/DJ0.mp3$;

- A second location is mainly a river with a few grass; in the different records, you can mainly hear water flow and a few sounds from natural environment (resp. $AS2/AS1.mp3$, $/OB2/OB1.mp3$, $DJ2/DJ1.mp3$);
- A third location is including a large part of grassland; soft natural sounds such as birds and wind, harp and flute emphasize these quiet areas (resp. $AS2/AS2.mp3$, $/OB2/OB2.mp3$, $/DJ2/DJ2.mp3$).

Figure 4: Graphic interface of the prototype plugin: colors assignment for an urban location
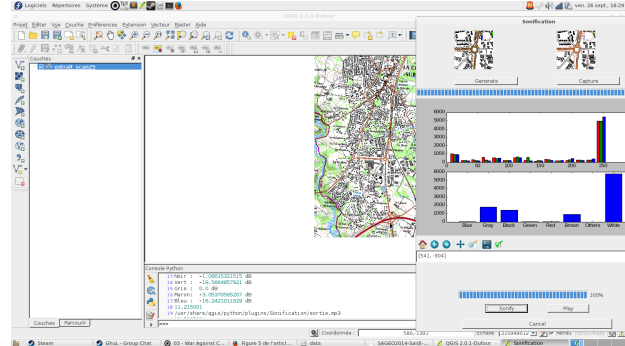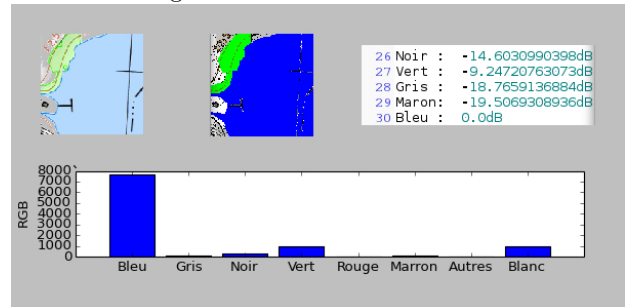

Figure 5: A water environment.

4.2 Usability tests

We tested the method with 54 participants including 16 blind or visually-impaired people, 16 students in geography and 23 pupils from elementary school. The participants were most of the time young. However, one was 65
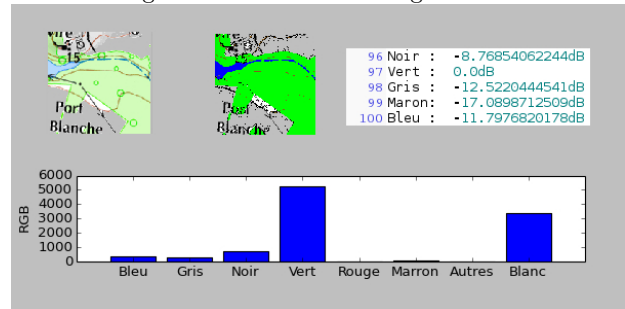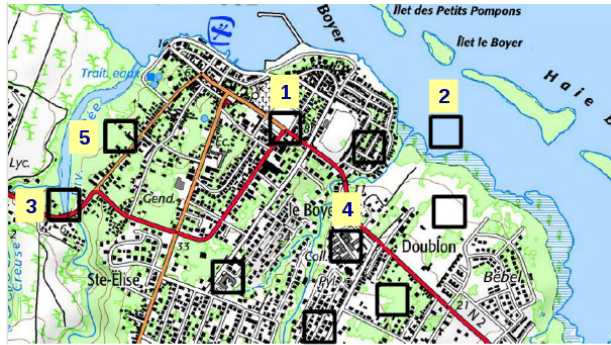
Figure 6: Green areas and grassland.

Figure 7: Usability tests with sighted and blind people: finding the 5 sonificated locations among 10 candidates.

Source: Dorian Roussel

years old and 4 were between 25 and 34 years old. The test presented here is a part of the whole study. It is quite simple (cf Figure 7): after an introduction about the test objectives, participants hearing was trained with a series of sonorous and musical sequences supposed to represent a set of colors that compose the image. Once the correspondence between colors and sounds effective, we proposed to all the participants a set of 10 candidate square locations. 5 different sonorous compositions were then provided and the participants had to match them with 5 of the locations they think they represent. For blind people, we just orally listed the locations and especially asked about the colors suspected to be in the windows of each location.

A majority of the participants succeeded in finding the relevant patterns. For instance, the first pattern (see nb. 1 in Figure 7) was correctly assigned by 34 people. The second pattern was even simpler and only 6 people did not find the good matching. The third pattern was slightly more complex because it was a mixture of several balanced sounds. In this case, pupils had difficulties to fix this problem (50% of good answers) while 11 blind and vision-impaired people (among 15) succeeded. This shows the compensatory capability developed by those. Similar results were obtained with the fourth pattern, where only 30% of the sighted people provided the good results, while 67% of blind people succeeded in finding the correct assignment. However, they are globally older in this group. The fifth pattern was somehow subtle due to the insertion of a little black and orange in a dominant green which required to prick up one's ears. Here about 70% of the students succeeded and only 30% for the pupils. This shows that experience is required to learn and to use sonorous mapping, whatever your vision capability. Complementary studies will be provided to adapt and improve the learning stage of the process and to check what sort of sounds and music speak the best way to sighted or visually impaired people.

5   Conclusion

We presented an original approach to sonificate images using a dedicated GIS plugin prototype. Some usability tests were provided and showed that in most of the cases, such a tool may be useful to represent colored spatial patterns using sonorous sequences and even short music compositions. It also enhanced the capacity of blind people to analyze and take into account sounds in their environment representation, sometimes in a better way than sighted people due to an efficient sense compensation.

However, there is still research to develop to generalize these first promising results (made from a little, and probably not representative, population sample). Moreover, images also show some text (generally in black) that may impair the colored composition analysis provided by the plugin. Passing to vector objects instead of colors will also open new interesting fields, including space harmony, topological organization and path description.

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