Tactile Point Patterns on Geographical Maps for Visually Impaired Users

A report submitted for credit within a CSE303 course

by

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Abstract

In this report, we introduce an algorithm designed to transform geographical maps into representations featuring distinct point patterns, effectively conveying the spatial information inherent in the original map. We begin with stating the purpose and importance of the research by talking about tactile graphics for the visually impaired. Then, we describe the process, in which tactile point patterns derived from Voronoi diagrams, along with contour extraction, offer a tangible representation of geographic features. These patterns serve as a foundation for a tactile map that conveys scalar information through touch. We analyze the results, share our observations, and talk about possible extensions of our work.

Contents

Chapter 1

Introduction

Visually impaired people represent a significant part of the population, there are up to 30 million blind and partially sighted persons in geographical Europe [1]. Despite ongoing efforts to enhance inclusivity for disabled individuals, infographics remain inaccessible to the visually impaired community.

The lack of accessibility is particularly detrimental within STEM disciplines (Science, Technology, Engineering, and Mathematics) where graphics play an important role.
Tactile graphics are raised, textured, or embossed images that are designed to be touched and felt, providing a tactile representation of visual information for individuals with visual impairments.[2]. Such graphics are crucial for social adaptation of visually impaired people in fields like map navigation and audio guidance during travel. Research underscores the irreplaceable role of tactile graphics technologies in the education and social lives of BVI individuals [3].
Some alternatives attempt to fulfill the same role, such as text descriptions, manually created tactile graphics, or refreshable Braille displays. However, they face limitations in handling complex graphics and require expertise, are often time-consuming and pose cost challenges. Hence, there is a need for meticulous research into options that are cost-effective, user-friendly, and efficient.

Building upon this motivation, our project aims to develop a tactile representation of geographical maps tailored for visually impaired users.
In pursuit of this goal, we have developed an algorithm that extracts distinct regions on a map, each corresponding to a value of the scalar function derived from said map, such as altitude or population density.
We start with a geographical map without any labeling and in which any contours, if they exist, are drawn in black. Our algorithm offers contour extraction, optionally incorporating Voronoi discretization within each contour. Subsequently, specific intensity values are assigned to the delineated areas within the contours. Ultimately, point patterns are created to represent these intensity values. Ultimately, these tactile point pattern maps can serve as the foundation for fully functional tactile graphics, contingent upon the verification of point pattern readability and the addition of labels and titles.

This algorithmic approach lays the groundwork for creating tactile representations of geographical maps, addressing diverse user needs and promoting inclusivity in map accessibility.

Chapter 2

Background information

In this section, we provide background information about spatial interpolation as well as structures that can be used in conjunction with interpolation techniques to analyze and represent spatial data. We offer an overview of point pattern analysis, distinguishing between correlation and density. Some of the preceding studies regarding tactile diagrams are also introduced.

2.1 Spatial Interpolation and related methods

2.1.1 Spatial Interpolation

Spatial interpolation is a technique used to estimate values at unmeasured locations within a study area based on known sampled values at sampled locations [4]. The objective is to create a continuous surface or map representing the progression of variables across space. There exist many different interpolation methods such as kriging, inverse distance weighting, and spline interpolation. They require data collected at discrete points within the study area. The generated output is a complete, continuous representation of the variable, allowing for a more comprehensive understanding of its spatial distribution. Spatial interpolation has a large range of applications, especially in geographical information systems (GIS), environmental modeling, and other fields where spatial data analysis is crucial.

2.1.2 Voronoi Diagrams

Voronoi diagrams are geometric structures that partition a plane into regions based on proximity to a set of reference points. [5]. The construction consists of separated regions called Voronoi cells, providing a spatial segmentation of the plane. Each point in a given cell is closer to its associated seed point than to any other. Thus, the construction of Voronoi cells relies closely on the selection of the initial points and their significance as a whole to accurately represent the entirety of the information. Voronoi diagrams exhibit useful geometric properties such as symmetry and convexity, making them valuable in various geometric and computational applications. As a consequence, this method is widely used in computational geometry or geography for tasks such as nearest neighbor search and spatial interpolation. Voronoi diagrams have a dual relationship with Delaunay triangulation, in a way that the edges of the Voronoi cells connect the circumcenters of the corresponding Delaunay triangles.

2.1.3 Delaunay Triangulation

Delaunay triangulation is a geometric method for connecting a set of points in a way that maximizes the minimum angle of all the triangles formed, leading to well-shaped triangles that avoid acute angles [6]. Another geometric property is that the circumcircle of any triangle in the Delaunay triangulation contains no other input points. The triangulation creates non-overlapping triangles, and each point is a vertex of one or more triangles. The produced triangles are often more regular and better shaped than those in other triangulations, which is one of the advantages of this method. It is used for spatial analysis purposes, including spatial interpolation, computational geometry, and mesh generation.

2.2 Point pattern analysis

The characteristics of a point pattern relies on two crucial factors: the density of point placement and the spatial relationships among the points [7]. On the one hand, density refers to how closely or sparsely points are distributed in a given space. It focuses on the abundance of points within the area of interest. On the other hand, point correlation involves the analysis of how points are positioned relative to each other in a two-dimensional space. This analysis helps discern whether points tend to cluster closely or systematically spread apart. Various methods, such as spectral and spatial tools, have been developed to analyze point correlation. Correlation among points can be measured using tools such as Pair Correlation Function (PCF). To provide a quick overview, the PCF is defined in terms of the intensity λ and product density ρ of a point process. It is expressed as the ratio of the product density $\rho(r)$ to the intensity λ, where $\rho(r)$ represents the probability of having points at a distance r from each other in an isotropic case.

2.3 Related work

2.3.1 Understanding tactile graphics exploration

In education, common tactile graphics for the visually impaired include raised-line graphics on Swell Touch paper, explored through finger touch. Due to a lack of standardized design processes, researchers [8] have investigated the exploration methods of visually impaired individuals when interacting with raised-line graphics. The study focused on finger behavior, specifically tactile fixations, revealing significant differences in fixation number and duration across graphics, tasks, and using both index fingers. Notably, more fixations occurred on the left hand, while longer durations were observed on the right hand. The study also identified three bimanual exploration strategies, involving fixed right-hand anchor points, alternating hands, and a chaining hands exploration pattern.

2.3.2 Encoding color in point patterns

This section outlines a dynamic tactile image rendering framework [7] that adjusts point densities and correlations for generating patterns. It starts with a reference image using SVG patterns, representing contours with color and intensity dictating point density. The framework generates points, initially with random correlations and later introduces fixed points along edges for enhanced visibility. A radial density function, based on the PCF introduced in 2.2, captures variations, and an optimization process refines distribution. The image assembles distinct point patterns, ensuring smooth transitions between correlations, facilitating varied printing methods and enhancing visual recognition.

Chapter 3

Conception

In this chapter, we describe the design choices for our image processing pipeline. Then, we provide a more precise description of the algorithm, explaining the different steps involved, in which Voronoi diagrams, contours, and patterns are generated based on the input image and specified parameters.

3.1 Design choices

The code in C++ is organized into multiple files, each responsible for a specific functionality, with the main functionality leading the way to sampling, contouring, discretization, and finally pattern generation. The different functionalities are defined using a class-based design. This modular structure along with an object-oriented approach allow better code organization, readability, as well as encapsulation of related functionality, making it straightforward to enhance and improve.

The integration of external libraries is necessary for various tasks. The code leverages the OpenCV library for image processing tasks. This library is used for reading and manipulating images, contour extraction, and image writing. Another library included is the Boost library providing a robust implementation for geometric operations, in particular Voronoi diagram computation.

3.2 Description of the framework

The image processing is performed as follows. The input image is read into an OpenCV matrix in grayscale. Depending on the chosen translation type which is set directly from command line, different transformations can be applied. One option is to draw only the contours ($TRANSLATION = 0$) and directly output the resulting image. Otherwise, either only the outer borders ($TRANSLATION = 1$) or the borders of every region ($TRANSLATION = 2$) are considered, along with a discretization with a Voronoi construction, and pattern generation. Finally, the resulting image is saved.

Let us provide more details about each step of the pipeline 3.1 .

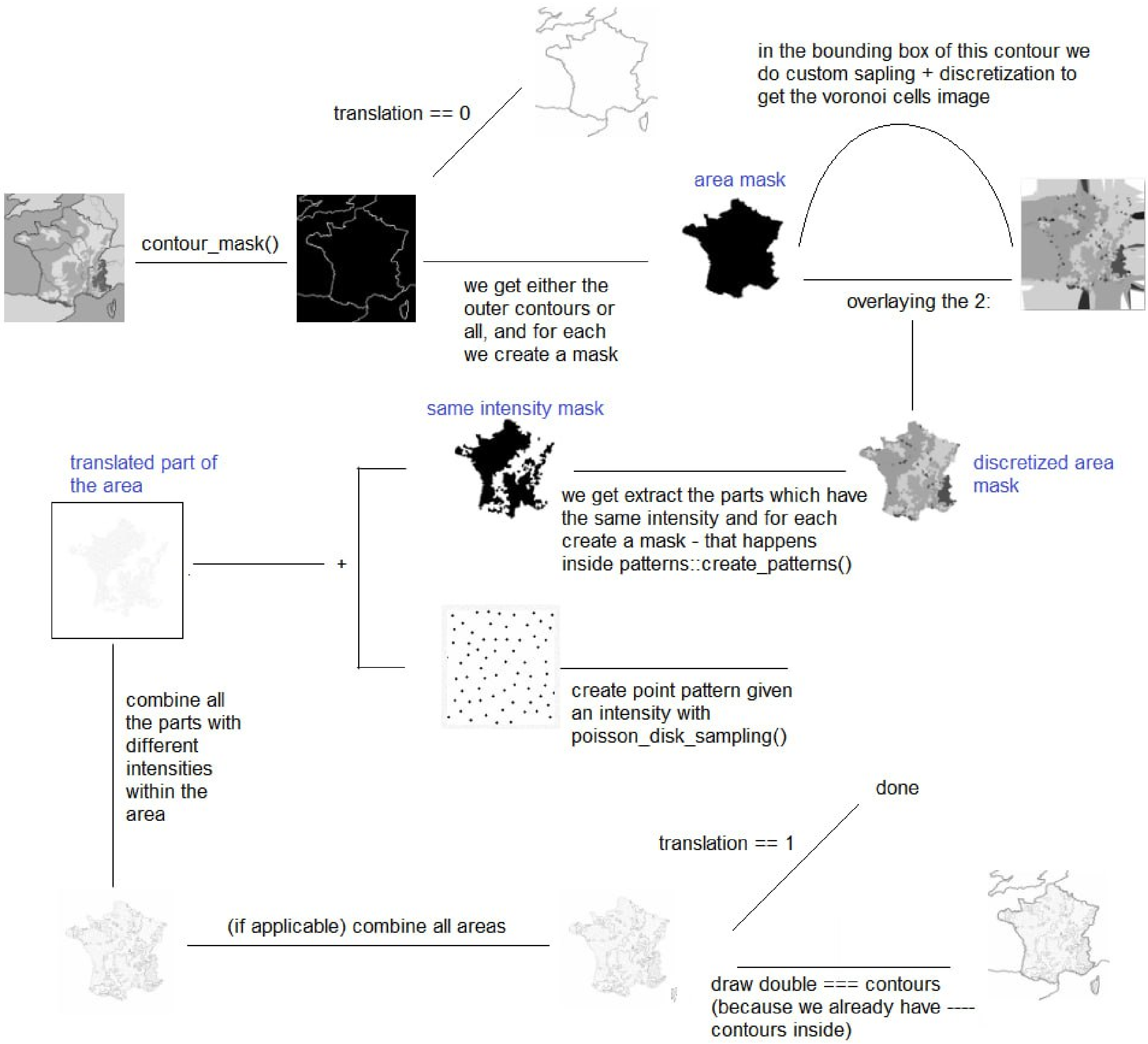

Figure 3.1: Scheme of the pipeline

For each contouring option, the initial step involves creating a binary mask of the existing contours on the map through thresholding. Subsequently, dilation is applied to enhance continuity in the contour representation. The binary mask provided in an intermediate image highlights the contours and simplifies the representation of the input image to facilitate contour extraction.

Then, if the map is to be discretized, the relevant contours are extracted using the OpenCV function findContours. A separate binary mask is created for every contour. Following the extraction of outer or region borders, the discretization is based on a Voronoi construction method, mainly using the Boost library.

We work on the contours independently. For each contour, the discretization starts by performing a custom sampling. The approach is iterative, an initial Voronoi diagram inside the specific contour. A new point is added in each iteration, which number is determined by the area of the contour's bounding box. We note that only relevant points are added to the sampling. Indeed, from a randomly generated point, we measure both its real intensity and its expected intensity that is based on the current Voronoi diagram, compare the values and add the point to the sampling if the difference is significant (the threshold parameter $INTENSITY\_DIF$ can be modified). After the addition of a point in the sampling, the Voronoi diagram is reconstructed taking into account the new point, to be used as a reference for the addition of a next point.

Once the point sampling is completed, it is used to draw a final Voronoi diagram on the corresponding contour of the output image. We then iterate over the Voronoi cells of this region and assign an intensity value to each cell based on the pixel intensity at the cell's center in the input image. Finally, the cell region in the output image is filled with the determined intensity. These steps are repeated for each and every area.

For each contour, we derive a discretized mask and isolate the parts with identical intensities. Using this intensity value, we generate a blue noise point pattern through Poisson disk distributions [9]. The pattern is applied on the corresponding parts of the area, after which the pattern applications of the different parts of the area are combined within a single area translation.

A further step consists of unifying all the area translations on the output map. In instances of region extraction, the image requires delineating double-line outer contours to distinguish them from the single-line contours within the map.

Chapter 4

Results

In this chapter, we present our results regarding the output images that were obtained on a set of maps [10]. We introduce instances of maps with and without regions, along with their translations. Then, we proceed to the comparison of different sampling methods with ours. Through this analysis, we aim to outline the relevance and effectiveness of our custom sampling method.

4.1 Example of translation without regions

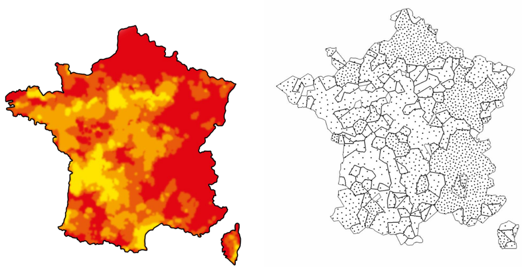

Figure 4.1: Soil drought indicator in 2022: from the original map to its translation

In figure 4.1 we present an example of a translation from a map of France conveying information about soil drought into a graphic with delimited areas of different point patterns. The original map offers no distinct regions, aligning with the parameter set as $TRANSLATION = 1$ in the algorithm. It is noteworthy that the delineated areas prove to be pertinent. Indeed, they strike a balance by conveying sufficiently precise information and not being excessively numerous, ensuring that even in compact spaces, the differences in point pattern densities remain discernible by eye (see $Chapter 5$).

4.2 Example of translation with regions

In figure 4.2, we showcase an illustration derived from a map of France about rain deficit. The transformation ($TRANSLATION = 2$) into a point pattern graphic with distinct regions is displayed, featuring regions demarcated by double-line segments which distinctly delineate between regions and pattern boundaries. Notably, the point pattern generation has been executed autonomously within each region, ensuring that patterns do not overlap along contours.

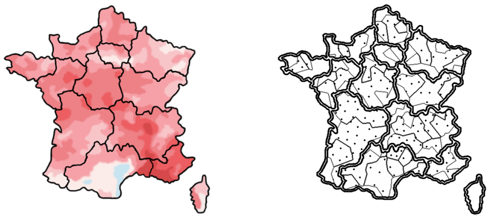

Figure 4.2: Rain deficit: from the original map to its translation

4.3 Comparison of sampling methods

In figure 4.3, we confront different sampling methods on a grayscale map. Four distinct sampling techniques (random, uniform, grid, and our custom approach) have been applied. Following the discretization phase, the outcomes are compared against the original grayscale image. Pixels are inspected one by one and their values are used to compute two independent metrics, namely the percentage of identical pixels and the mean square error. We observe that our custom sampling method outperforms others, boasting the highest similarity percentage and the lowest mean square error.

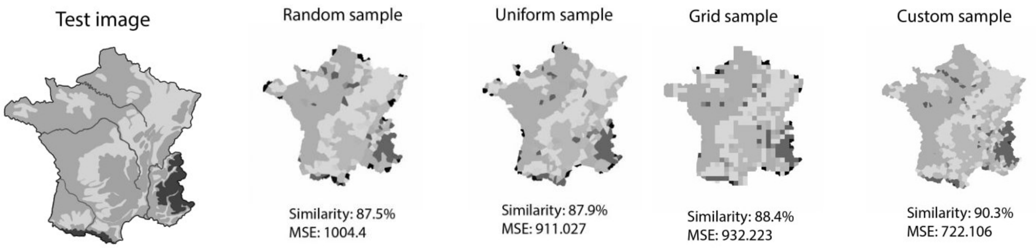

Figure 4.3: Comparison of four sampling methods, including ours, on a test image

As a side note, we have attempted to introduce the natural neighbour interpolation based on delaunay triangulation in the discretization step of our algorithm. Indeed, this method is particularly relevant for preserving local feature variations and adapting to irregularly shaped regions. Nevertheless, upon integrating the natural neighbor method and assessing the algorithm using a reference map, the results were perplexing; certain white lines disrupted the sampling process, evident in the generated patterns as well. Due to time constraints and challenges in understanding the highly intricate code [11], achieving satisfactory results proved elusive.

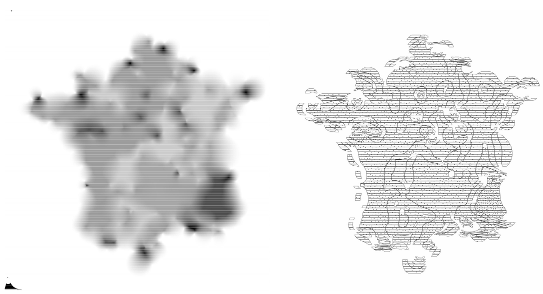

Figure 4.4: Inconclusive attempt with NN interpolation

Chapter 5

Discussion

We have developed an image processing algorithm capable of translating geographical maps into output images partitioned into regions of varying intensity.

We can propose the following improvements for our algorithm.

Following pattern generation, a further step would be to adjust the algorithm to account for the design principles of tactile graphics. There are recommendations [12] to follow regarding dots and heightened contours, their spacing and size in order to ensure readability by visually impaired users. Moreover, it would be necessary to add labelings and keys (used to explain textures) respecting the standards for tactile graphics [13]. Subsequently, these complete graphics could undergo printing and be subjected to user studies to assess the accuracy and relevance of our algorithm in real-world applications.

Another improvement proposal pertains to the algorithmic choice of using Voronoi construction for discretization. While our current approach is suitable given the absence of constraints on sample points and the separate application of discretization on contours of different sizes, it's noteworthy that Delaunay triangulation algorithms are often computationally more efficient. These algorithms, requiring fewer sample points, could have been considered as an alternative. The decision to employ Voronoi diagrams is justified by their effectiveness in capturing proximity relationships between points and regions.

One final possible extension could be implementing a more user-friendly interface to improve user experience. Presently, users need to possess knowledge of C++ to execute the code by running *./MapTranslator <image_path> <translation>* where they specify the image path and the translation type. We could also expand the set of modifiable variables to enhance flexibility, for instance the number of iterations in the Voronoi discretization for each contour which dictates the number of point samples in this specific contour. This flexibility would empower users to fine-tune the algorithm according to specific requirements without manual code modifications.

By incorporating these suggestions, we aim to enhance the versatility and computational efficiency of our algorithm, as well as its accessibility to a broader audience with varying levels of programming expertise and specific customization needs. It would make it well-suited for a broader range of applications and scenarios.

To conclude, engaging in this challenging project was a source of satisfaction as it underscores the practical applications of computer science and mathematics in addressing real-world challenges.

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