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Geographic Data Visualizations Using Heat Maps with Support for Color Blind Users

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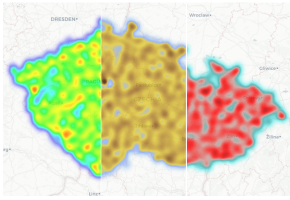

Abstract
Data visualization on a map is a tool which is being used in fields such as industry, political science, education and, now more than ever, epidemiology. Heat map is a type of geospatial visualization which displays intensity of observed phenomenon using color spectrum. However, people with visual impairment, commonly known as color blindness, are being limited in usage of these tools as colors as perceived by them are at best misleading, and at worse totally indistinguishable from each other. This makes it hard to even read displayed data, while making it practically impossible to create a visualization of their while being sure that they picked the right color spectrum. To address this issue I have extended an existing solution – geovisualization application Geovisto with heat map layer which provides color schemes for people with most common forms of color blindness. By using the right scheme a person with color blindness can be sure that they are seeing true colors which are not being distorted by their specific type of impairment. It's then possible to switch to generally used blue-green-red color spectrum and publish it with confidence that people without any form of color blindness are seeing the right result. I have created a set of color schemes for users with dichromacy using tools which try to emulate color perception for color blind people.

Keywords: Heat map — Color blindness — Geovisualization

Supplementary Material: Live Demo — Downloadable Code

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1. Introduction

Data is often bound to certain locations. Especially, when dealing with big amounts of data, it's crucial to have ability to visualize them. This enables the reader of these data to analyze them much quicker than if they were just reading those data from table. For spatially-bound data, there is no better option than to use thematic maps. Thematic map is a type of map which displays locations such as cities or rivers only for user orientation while it's main function lies in data visualization [1]. This work is focused on one of many types of thematic maps – heat map.

Heat map is used to find density of houses, crime reports and much more [2]. As there is inexhaustible volume of potential data of different kinds, there is a need for a tool which is able to visualize generic data. The typical heat map also uses color spectrum ranging from cold to warm and light to dark, blue-green-red being the most used. This color spectrum offers poor visibility for people with color blindness. Color blindness is a decreased ability to see colors or differences in similar colors. According to [3], there is about 8% of males and 0.5% of females affected by red/green color blindness. There are two types of red/green color blindness called *protanopia* and *deuteranopia*. Even rarer form of color blindness characterized by the inability to see blue/yellow is called *tritanopia*. Since blue, green, yellow and red are colors typically used in heat map color spectrum, people with some kind of color vision deficiency might find themselves unable to work with these maps.

While there are other means of differentiating intensity than using different colors or color shades, they are not easily applied to the heat map. One such example might be map hatching - this technique works great for data maps such as choropleths, where there are clear borders between individual areas of varying intensity. Trying to apply this technique to the heat map, where the intensity is changing gradually is challenging. Also, Tufte in his work [4] speaks against using hatching or different patterns as a means to differentiate areas, as it tends to create visual confusion when used excessively.

For people diagnosed with *monochromacy*, who cannot see colors at all, it might be reasonable to use dot density map instead of heat map. However, this map focuses only on the *location* of observed phenomenon, while the heat map also works with *intensity*.

Several GIS[1] are able to produce heat maps, for example ArcGIS[2]. While most GIS are able to create heat map from generic data sets, they also tend to be expensive. To my best knowledge I do not know any GIS software with support for users with color vision deficiency, even though cartographer can use tools such as ColorBrewer[3] to pick colorblind safe color palette when creating data maps. There are several programming libraries which can be used to create heat maps, however as far as I know none of them offers the option to use colorblind-safe color schemes.

To address this issue, I extended Geovisto – an open-source geovisualization software – with the heat map layer. As all the other layers that Geovisto offers, it can be used to visualize generic data in JSON format thanks to data flattening. This layer provides user with three color schemes, two of them being targeted at color blind users.

2. How does the heat map work

Heat map shows the density of points as a raster area. Those areas are formed by creating a buffer zone around each point in dataset. All points must use the same radius for their buffer zones. Areas in which those zones overlap are then considered as areas with higher intensity and colored accordingly. This technique of buffer-overlapping is shown in Figure 1.

To place these points with buffer zones, a pair consisting of *latitude* and *longitude* is needed, as well as the number indicating the radius of buffer zones. There are other possible parameters which I will describe in the section about my heat map layer implementation in Geovisto.

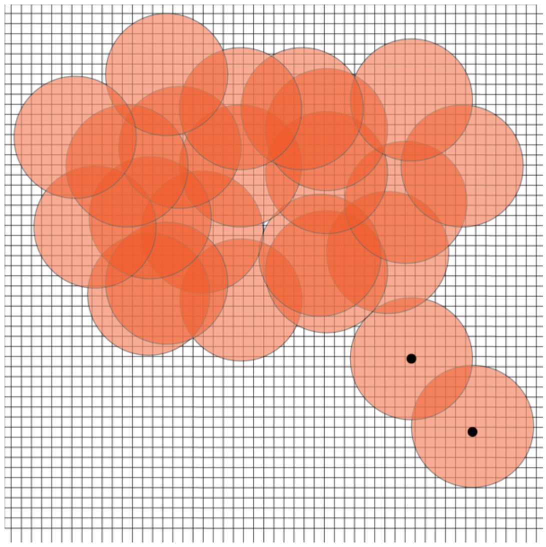

Figure 1. This figure shows how buffer zones are created for each point in raster area. In computer graphics, raster area is rectangular grid of pixels which may have different colors. Buffer zone is a circular area, in this Figure red, which is constructed around each point in dataset. Overlapping of buffer zones results in higher observed intensity. It can be noted that this might create areas of high intensity in places where there are actually no points located. For this reason interactive heat maps typically change their radius on zoom enabling the user to find the precise location of each occurrence of observed variable.[4]

3. Heat Map Layer Implementation

I created heat map layer as an extension of Geovisto. Geovisto is a tool combining the advantages of authoring systems and programmable libraries. It is a web based application adjustable using UI and programmaticaly [5]. It is written in JavaScript using Leaflet[5] and D3.js[6] and exports a React-based component. As Figure 2 shows, it's composed of `Map` which is a React component wrapping the entire application, `Map`

[1]Geographic Infromation System

[2]See https://doc.arcgis.com/en/insights/latest/create/heat-maps.htm

[3]Available: https://colorbrewer2.org/

[4]Taken from [2]

[5]https://leafletjs.com/

[6]https://d3js.org/

`core` and `Tools`.

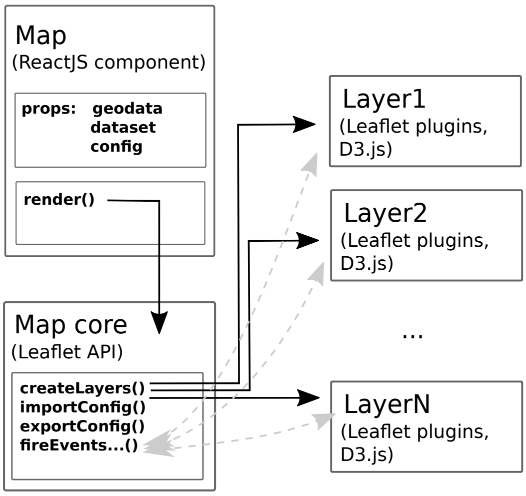

Figure 2. React component renders and wraps the Map core which ten creates Tools and dispatch their events.

Core uses Leaflet API to manipulate with map, read data files and transforms them into one-dimensional array. These flat structures are then use to map data dimensions (represented by JSON object keys) to layer dimensions (such as location or intensity). It also exports and imports user configuration files. Based on configuration files, it creates tools which provide functionality.

To create a heat map layer, I had to create a new tool using plugin `Leaflet.heat`[7] by Vladimir Agafonkin, the autor of the Leaflet library.

3.1 Heat Map Layer Settings

As shown in Figure 3, the heat map takes seven arguments. The first two *Latitude* and *Longitude* place the points in the map. *Intensity* is a number which determines how many points are placed in the map for one pair of $(lat; lng)$. *Radius* specifies the radius of the buffer zone and *Blur* is responsible for how much the color fades from hot to cold for one point, the smaller the number the faster the transition. *Zoom/Intensity* specifies at which level of zoom the points reach maximum intensity (as intensity scales with zoom). *Gradient* serves to choose the color scheme. I will write more about different kinds of gradients and how I created them in the next section. While *Latitude*, *Longitude* and *Intensity* are mapped to object keys from data file, the remaining parameters are set manually. This is because different data sets require different settings which user might not know before he visualizes this data set.

[7]Available from: `https://github.com/Leaflet/Leaflet.heat`

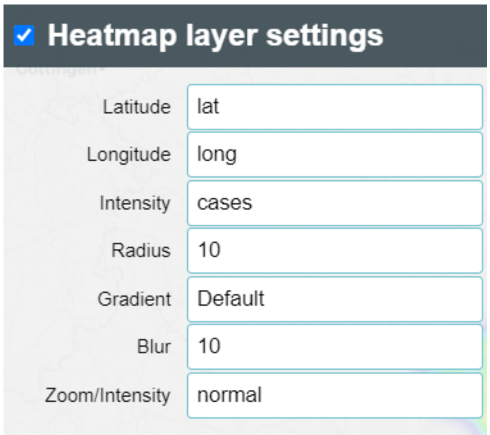

Figure 3. Heat map settings panel UI.

4. Choosing the right color gradients

Obviously, it is not possible to see through other people's eyes but fortunately, there are tools available which try to mimic what color blind person would see for given color palette.

One such tool is available at the website[8] by David Nichols. For a given palette of colors, it shows what a person with protanopia, deuteranopia and tritanopia would see. The vision simulation is demonstrated in Figure 4.

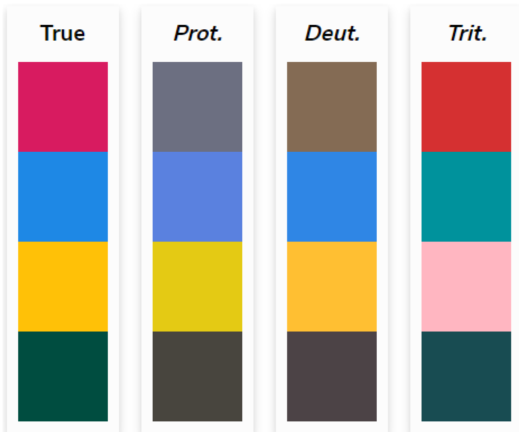

Figure 4. True colors and their perception by person with protanopia, deuteranopia and tritanopia respectively.

The default gradient which is being used by the *Leaflet.heat* or Google Maps API is shown in Figure 5. As can be seen this palette is inappropriate for users with color vision deficiency because almost every color in the palette gets distorted heavily.

To solve the problem, I have chosen colors which would not get distorted for people with these kinds of color blindness. The result is shown in Figures 6

[8]See `https://davidmathlogic.com/colorblind/`

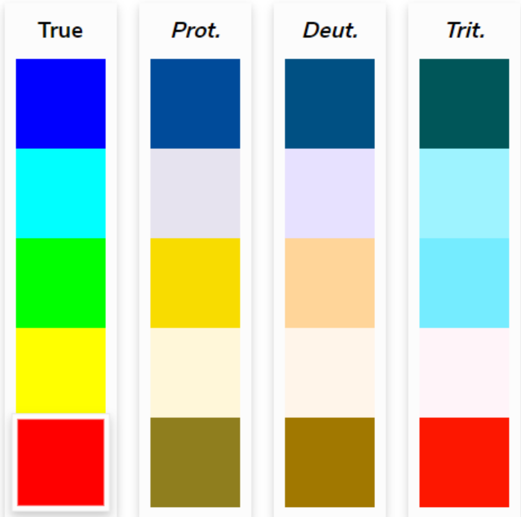

Figure 5. Color palette of the Default gradient in heat map layer.

and 7. There is little to none distortion in the colors as seen by people with color vision deficiency and by people with healthy eyes alike. Also, the traditional cold-to-hot color scheme is kept.

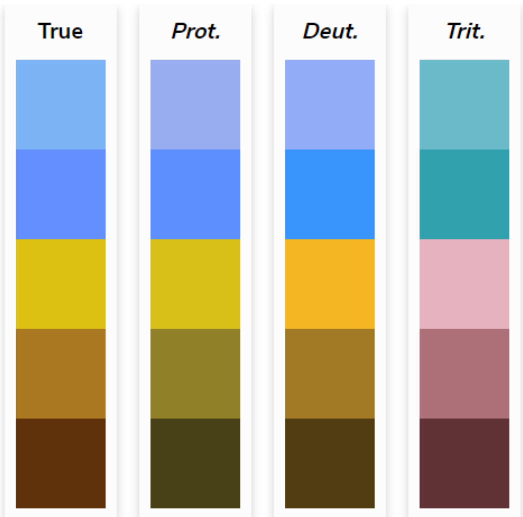

Figure 6. People affected by protanopia or deutranopia cannot distinguish between red and green so those colors were omitted.

5. Examples of Data Visualization

I have used data set regarding COVID-19 pandemic provided by the Czech Ministry of Health[9]. This data set contains date and new positively tested cases, name of town or village where this person lives and more. First, I accumulated data across time for every village and town and then, using Nominatim geocoding

[9]Available at: `https://onemocneni-aktualne.mzcr.cz/api/v2/covid-19/orp.json`

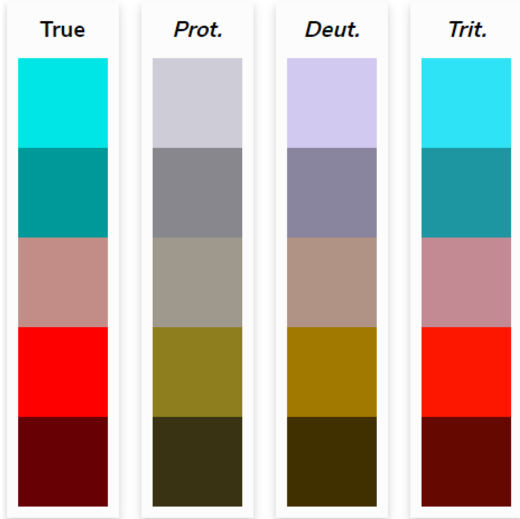

Figure 7. In order to keep colors being perceived by people with tritanopia as true I needed to choose from the green-to-red palette.

API[10], created pairs of $(lat; lng)$ for each record. In the following Figures (8, 9, 10, 11, 12 and 13) there are results of visualization of this data set.

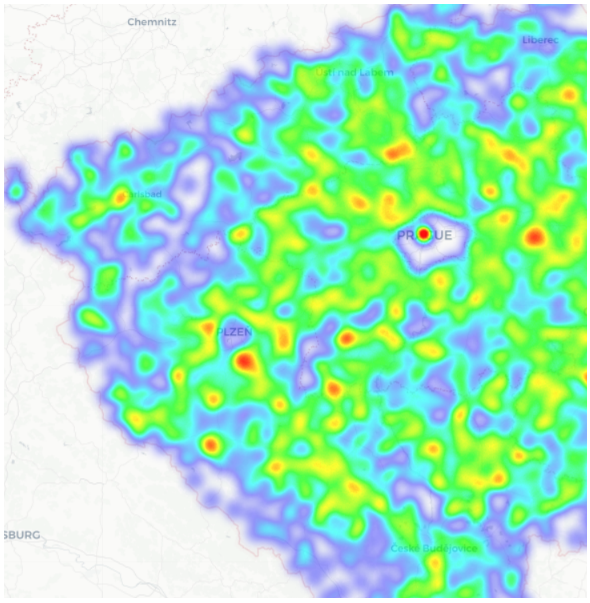

Figure 8. Cumulative COVID-19 cases in the western and central Bohemia using the Default gradient.

There is some loss of detail in the colorblind-safe gradients, as the broader the color spectrum the richer the color transition.

6. Testing with Colorblind Subjects

The heatmap solution with different gradients for different kinds of color blindness has been tested on two

[10]`https://nominatim.org/release-docs/latest/api/Overview/`

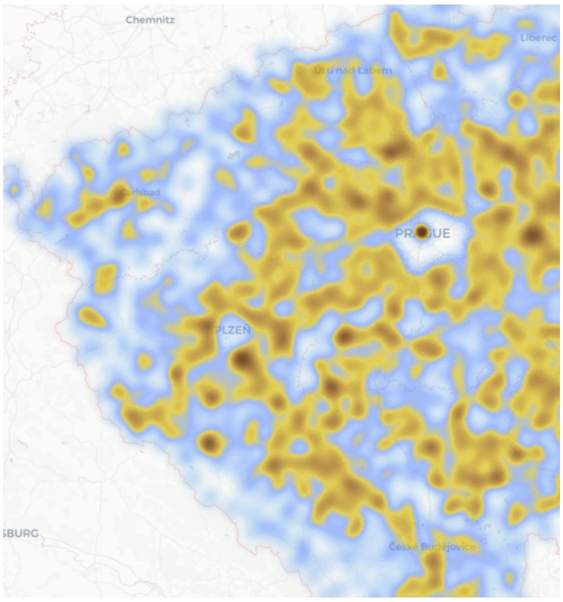

Figure 9. The same area as in Figure 8 seen with the Deuteranopia/Protanopia gradient.

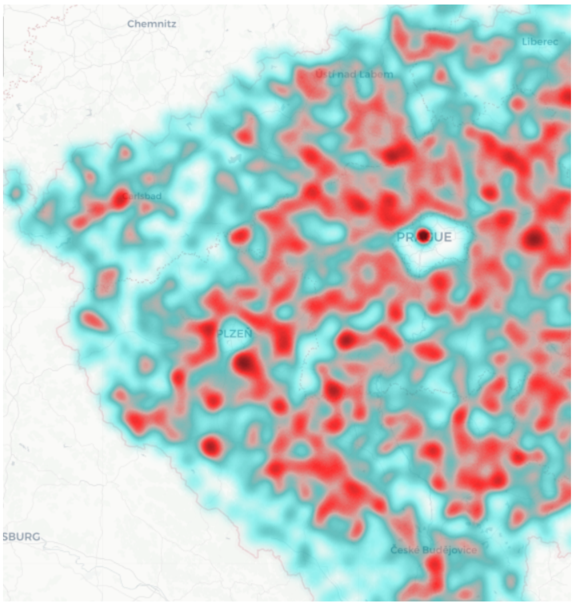

Figure 10. The Tritanopia gradient gives the same amount of detail as the Deuteranopa/Protanopia gradient shown in picture 9.

subjects. Neither the first nor the second subject knew their precise diagnose. Using the aforementioned tool by David Nichols and another color blindness simulator[11] it was estimated that the first person suffers from light deuteranopia, also known as *deuteranomaly*.The second subject has moderate case of protanopia.

For the first respondent, the default gradient was the most useful. Although they saw a slight distortion in green color, they were still able to pinpoint spots

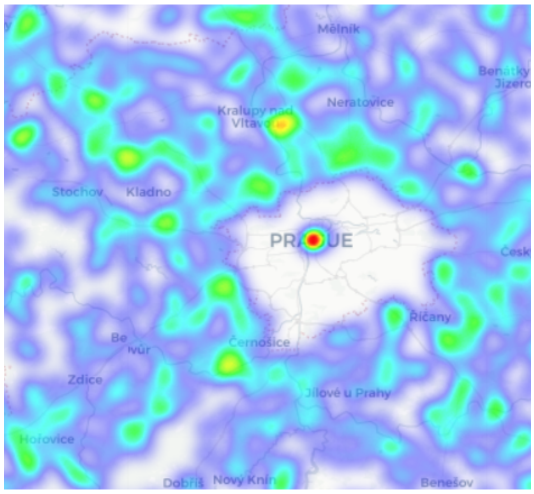

Figure 11. Intensity changes with zoom.

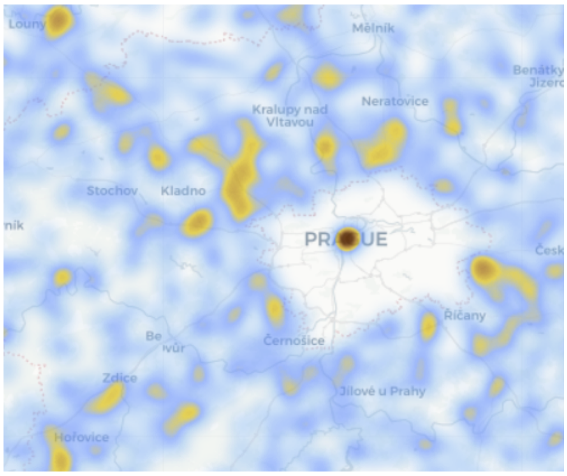

Figure 12. Zoomed in area of Central Bohemian Region with Deuteranopia/Protanopia gradient.

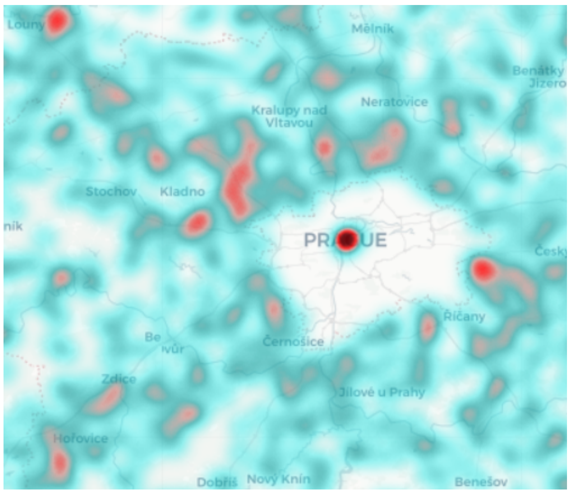

Figure 13. Tritanopia gradient when zoomed in.

with low, moderate and high intensity with perfect precision.

The second respondent, however, was not able to work with default gradient as well as the first one.

[11] https://pilestone.com/pages/color-blindness-simulator-1