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A new graph-based metric for modeling aggregated gaze behavior differences during map reading

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Abstract:

Map reading constitutes a complex process that can be affected by several factors, including cartographic design choices, the descriptive characteristics of map readers, and map viewing conditions. In order to understand how map users interpret maps, it is essential to examine both perceptual and cognitive issues related to the map reading process. Research studies in the aforementioned domain employ well-established qualitative and quantitative experimental methods towards the investigation of research hypotheses connected to the influential factors. Among the methods utilized, during the last decades, eye tracking has become a quite popular technique that substantially supports the examination of different topics on map perception and map cognition (Krassanakis and Cybulski, 2021).

Eye movement analysis is based on the computation of simple or more sophisticated metrics while it is also supported by quantitative approaches, which involve the implementation of different visualization techniques. At the same time, gaze data analyses can describe either individual or aggregated visual behavior. Grayscale statistical heatmaps are (mainly) quantitative products that are developed considering the spatial distribution of raw gaze or fixation points data and aim to describe the spatial allocation of visual search activity during the observation of (audio)visual stimulus (Krassanakis, 2021). In practice, grayscale statistical heatmaps are generated after the implementation of a Gaussian filter considering the visual range of foveal vision. The result of this filtering is a grayscale image in which pixel values are normalized in a specific range and indicate the possibility of having activity inside this area. Hence, in eye tracking data analysis, grayscale statistical heatmaps could indicate the most salient locations of an observed region. In cartographic research, such output is very critical for the examination of the influence of different areas of interest (AOIs) inside a cartographic background, for comparing the strategies performed in different map designs and/or by individuals with different characteristics, as well as for feeding Artificial Intelligence (AI) algorithms towards modeling the visual attention and developing dedicated (cartographic-based) saliency models (Keskin et al., 2023).

In the present study, we introduce a new graph-based metric for modeling aggregated gaze behavior differences during map reading process. More specifically, the metric can be utilized to describe both quantitatively and qualitatively the difference between the gaze activity (pattern) on two different cartographic backgrounds based on eye tracking data collected either under free viewing conditions or during the execution of a specific map task. Cybulski and Krassanakis (2022) presented a methodological approach where specific indices, based on grayscale statistical heatmaps, are computed in order to describe the overall visual behavior inside a specific map stimulus. The new metric extends the aforementioned method by performing a comparison between two different grayscale statistical heatmaps with the same resolution and the same range of values. The first step for the generation of the graph-based metric involves the computation of the difference between the intensity values (for each pixel) of the two (input) grayscale statistical heatmaps. The result of this step is a new grayscale image that indicates the differences between the input heatmaps. In the next step, a graph is generated where the horizontal axis corresponds to the total number of the potential integer differences that could be appeared (e.g., 256 different values in the case that the intensities of the initial grayscale statistical heatmaps have a range between 0 and 255) while the vertical axis is the percentage of the pixels (normalized in the range between 0 and 1) whose absolute difference is equal or lower to the corresponding value (Figure 1). At this point, it is important to mention that, although we selected the specific interval for the horizontal axis, the graph can be generated based on different values.

For the practical implementation of the proposed method, EyeMMV toolbox (Krassanakis et al., 2014) in MATLAB and Python programming language are used to generate the grayscale statistical heatmaps and to compute the new metric correspondingly. The metric is implemented in an eye tracking dataset (Liaskos, 2023; Liaskos and Krassanakis, 2023) which involves eye movement recordings (recorded in 500 Hz using EyeLink® 1000 Plus) produced by 30 participants during the observation (under free viewing conditions) of 75 visual scenes (1920 x 1080 px). In detail, experimental

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visual scenes involve cartographic backgrounds derived by five popular web services (Google Maps, Wikimedia, Bing maps, ESRI, & OpenStreetMap), correspond to three different zoom levels (12z, 14z, & 16z) and portray, in each level, five different cities in Greece. The proposed metric is applied to all the possible couples of visual stimuli that correspond to the same zoom level, depict a common region and are provided by different services (150 combinations in total). The metric indicates the existing observation differences that are connected to the different salient locations. Additionally, in each generated graph, curve-fitting techniques are employed utilizing three distinct types of curves including a 6th degree polynomial, a rectangular hyperbola, as well as a sigmoid (logistic) function. Figure 1 illustrates a graphical representation of the basic steps of the followed approach. In this example, the presented visual stimuli have been adopted by Google Maps (up-left) and Wikimedia (down-left) online map services and depict the city of Kavala (Greece) at the zoom level of 16z. Moreover, in the provided example, a sigmoid function is fitted ($R^2 = 0.98$) in order to model the generated graph.

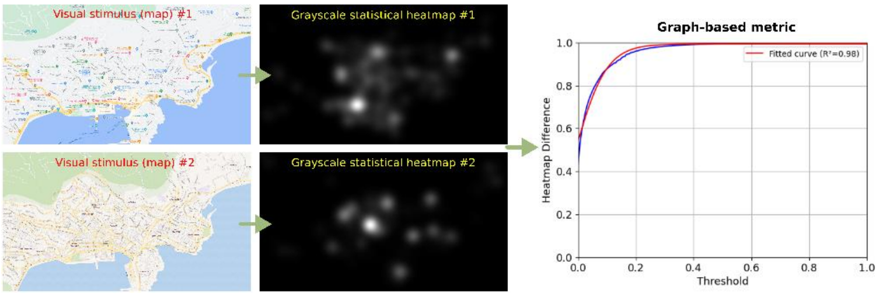

Figure 1. A graphical representation of the basic steps for the production of the introduced graph-based metric.

The results of the curve-fitting process indicate that the introduced graph-based metric can be mathematically modelled achieving values of R^2 metric quite close to the value of 1, in the majority of the cases. In this way, it is possible to quantitatively evaluate the differences in visual attention process between two different maps, since they are described by a one-dimensional curve. In general, higher and lower differences are observed for the combinations of OSM-ESRI at 12z and OSM-Google at 16z correspondingly. The introduced metric cannot be directly compared to typical (single number) indices applied in eye tracking studies since the following approach has been designed to indicate the overall searching behavior. However, the mathematical modeling of the existing differences allows their description utilizing even simpler arithmetic indices, such as area under curve (AUC) metric. Future research also involves the implementation of the introduced metric in larger datasets, including mouse tracking (e.g., Pappa and Krassanakis, 2022), under specific map tasks using different types of cartographic stimuli. Additionally, the metric can be utilized for the comparison of aggregated grayscale heatmaps produced by both eye and mouse movement data.

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