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Graphical similarity of cartographic symbols in a map-based search task

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Abstract:

The cognitive process of visual search plays a pivotal role in the interpretation of cartographic symbols during map reading activities. This process aligns with established theories in visual search, especially with similarity theory (Duncan & Humphreys, 1989). The theory assumes that for visual search to be fast and effective, the graphical difference between the target symbol (T) and other distractors (D) should be high enough to distinguish between these two (TD difference). Therefore, the search time for cartographic symbols should be long when the graphical similarity between T and D is high. Consequently, when the graphical similarity between T and D is low, the search time should be faster (Müller et al., 1990).

Within the cartographic domain, mapmakers frequently select symbols to depict points-of-interest from large repositories of symbols, such as those provided by Google Maps or Mapbox. A significant challenge emerges concerning the potential similarity among chosen symbols, as in complex map designs authors may lose overview of which symbols are in use on the map, and may not be able to avoid the selection of graphically similar symbols for semantically different aspects of the map. This resemblance becomes particularly noticeable when cartographers utilize comprehensive databases (Robinson et al., 2013), leading to symbols choices that may be difficult to discriminate or make reading the map harder for the user.

Therefore, the question arises: How can we quantify the differences in graphical similarity among various cartographic symbols? By establishing such metrics, cartographers could automatically detect graphically similar symbols, potentially posing issues for users, and replace them with less similar alternative designs. For this reason, we assessed an algorithm that enables the quantification of graphical similarity of cartographic symbols based on two metrics – "*ink ratio*" and the "*exclusive similarity*" (Latecki & Lakamper, 2000; Veltkamp. 2001). For a pair of symbols *A* and *B*, the following metrics are defined:

The "*ink ratio*" expresses the overall brightness ratio of two monochrome symbols, and is defined as the ratio of occupied pixels between two shapes:

$$\mathbf{inkRatio} = \frac{min(count(A), count(B))}{max(count(A), count(B))}$$

The "*exclusive similarity*" is defined as the total area covered by only one of the two shapes in relation to the common area:

$$\mathbf{similarityExclusive} = \frac{\text{commonPixels}}{\text{commonPixels} + \text{exclusivePixels}}$$

In order to verify whether these metrics can be applied to predict map reading performance, we conducted a controlled user study, in which participants were asked to find a given target icon on a map that also showed 15 distractor icons of varying similarity to the target. Our main hypothesis was higher similarity values would correspond with longer search times and eye movement patterns that reflect higher cognitive load. For the study, we used the “Maki” symbol set, from which we selected four subsets of symbols based on their basic geometric shapes, namely "orthogonal," "triangular," "round," and "intricate" (the latter being mainly composed of lines and fine geometric details). Within each set, one target symbol was identified in a way that maximized the number of potential distractors with similar overall brightness (a high

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ink ratio value) and a wide range of similarity values (using the *exclusive similarity* metric). For each chosen target symbol, sets of distractor symbols were chosen of high, medium, and low similarity to the target symbol, based on the ranked similarity of candidate symbols. In each trial of our experiment, one target symbol and 15 distractors symbols were randomly placed on a base map, and users were asked to find the target symbol.

Our results show that across all four subsets, users required more time to correctly identify and select the target symbol as the graphical similarity between the target symbol (T) and distractors (D) increased. In all sets of symbols, the median search times for highly similar symbols were 5-35% longer than for symbols with medium similarity, consistently exceeding at least 20% compared to symbols with low similarity. This observation was further supported by a higher number of fixations during searches with more similar T and D, as well as a significant decrease in scan path speed. This decrease in speed has been previously associated with more challenging map-based tasks (Keskin et al., 2019; 2020). Furthermore, our results show that symbols from the "round" subset were identified faster that other symbol shapes, at any level of graphical similarity, which corresponds with Klettner's (2019) assumption that circular-based symbols could be an important factor affecting search time.

The results of our study show that automated similarity analysis of large sets of map symbols is feasible, and can predict the time needed by the map user to locate and discriminate a symbol. The approach used in our study may be the basis for creating a fully automated "symbol analyzer" tool, which could point out problematic combinations of map symbols to map designers and thus contribute to better map designs.

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The outcomes of the analysis and visualization of symbol similarity are available in the following online notebooks:

https://observablehq.com/d/6f57cbd6f808e0b4

https://observablehq.com/d/87d48eed8b250451

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