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Suitability of colour hue, value, and transparency for geographic relevance encoding in mobile maps

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Abstract:

Mobile maps have become a commodity in the last decade. Despite the widespread use of mobile map apps, effectively presenting relevant geographically referenced information on small screens is still a challenge. Surprisingly, not much research has been dedicated to mobile map design issues. With presenting results from an empirical study on the suitability of the visual variables *colour hue*, *value*, and *transparency* for visually communicating the geographic relevance of points of interest (POI) on mobile maps, we aim at contributing to close this research gap.

The premise for our study is that mobile map viewing behaviour is influenced by visual attention allocation. This, in turn is determined by perceptual, bottom-up processes dependent on the visual saliency of stimuli, and cognitive, top-down processes which are dependent on task, goal, prior knowledge, and training.

With the study we address following research questions: 1) which of the three visual variables (*colour hue*, *value*, and *transparency*) optimally directs visual attention on small screen maps to the correct encoding of the geographic relevance? 2) do users understand the encoding of the three visual variables into three levels of high, medium and low geographic relevance of POI? and 3) do established cartographic conventions, such as *value* ('the darker, the more') and the traffic light metaphor (green hue as a positive/higher value, yellow as a medium value and red as a negative/lower value) work on small displays? These research questions address the saliency of POI symbols, their semantic understanding, and cartographic conventions. We expect to get insights into both perceptual (bottom-up component of attention) and cognitive (top-down component of attention) understanding of geographic relevance encodings in mobile map displays.

Methods: To evaluate the aptitude and effectivity of the three visual variables we conducted a test using the eye–tracking method. **Participants**: The participants were 27 subjects (13 female, 14 male) between 18 and 43 years old. They represent all strata of the population and had no previous knowledge of cartography (which was tested for in a pre-experimental questionnaire). **Material**: The stimuli were a total of 18 mobile maps, six for each visual variable, and were designed to fit an Apple iPhone 4 display. The base map, taken from OpenStreetMap, shows a road map of the Italian municipality of Trentola-Ducenta unknown to the study participants (see Figure 1). For *colour hue*, the variation is green, yellow, and red; for *value* the variation is between light, medium, and dark blue; for *transparency* the variation is between no, medium and high transparency of a violet colour hue. The base map and the three depicted POIs were the same for all maps, only the position of the POIs on the maps were modified (see Figure 1).

Figure 1. Mobile map stimuli for colour hue, value, and transparency condition.

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Study design: The study follows a within–subject design, i.e. each participant sees all three conditions, i.e. *colour hue*, *value*, and *transparency*. This independent variable (encoding of geographic relevance of the POIs) is then structured into three sub-levels. The dependent variables are *time to first fixation* (TFF), the *correctness of the order of the fixated symbols* (COFS), the correctness of the relevance ranking (CRR), and response time (RT). To address the bottom-up, stimulus driven aspect of geographic relevance processing, in the first part of the experiment participants have no prior knowledge. The 18 maps are presented to them on the screen scaled to the iPhone 4 size in randomised order to compensate for potential learning effects. In between, blank white screens with a black cross in the centre are shown to calibrate participants' gaze recorded by the eye–tracker. In the second part of the experiment participants had additional information in the form of a scenario. They had to imagine being in a foreign city and looking for a restaurant. This framing should set a goal, invoke expectations, and address the top-down processing. After a training phase, participants were asked to order the POI symbols displayed in the 18 maps from highly relevant to less relevant. This should provide insights, if they also had understood the semantic coding.

Main results: For the analysis of the gaze data recorded by the eye–tracker, areas of interest (AOI) were defined such to include the location of the three POI symbol on the map display. This allows the calculation of TFF, i.e. the time required by a participant to fixate a given symbol (i.e. its AOI) for the first time. COFS is measured as the proportion of maps, for which participants looked at the POIs in the correct order (from highly relevant to not relevant). Both, TFF and COFS revealed no significant differences between the three visual variables for the first part of the experiment where participants had no previous knowledge. In the second part, where participants knew, they were looking for a restaurant, TFF for *transparency* was significantly shorter than for *colour hue* and *value*. However, COFS was not significantly different. CRR, is like COFS, measured as the proportion of maps with correctly ranked relevancies (highly relevant, relevant, less relevant) per visual variable. *Colour hue* yields the lowest CRR (43.89%), while *transparency* received the highest CRR (80.67%). Value is in between with a CRR of 64.44%. A non-parametric ANOVA ($p < .05$) confirms significant differences between the three visual variables. CRR is significantly higher for *transparency* compared to *value* and *colour hue*. Moreover, CRR is significantly higher for *value* than for *colour hue*. RT, the time it took participants to submit their responses, is measured from the moment the map is displayed until the "Next" button is clicked. For analysis, response times per participant were averaged over the maps showing the same visual variable. A non-parametric ANOVA ($p < .05$) reveals that RT significantly differ between the three visual variables. *Transparency* has a significant lower RT than *colour hue* and *value*. However, RT for *value* is not significantly shorter than *colour hue*.

Discussion: The first part of our experiment yields no statistically significant differences between the three visual variables, which might be due to the lack of a concrete, goal-directed task. This is different from the second part of our experiment, where participants were given additional information for the visual search task before the test. This reflects a real situation where people already know what they want to search for at the beginning. Our results suggest that only the visual variable *transparency* seems to reliably encode geographic relevance and is intuitively and correctly perceived by participants. For *colour hue* and *value* participants were not able to consistently detect the symbol with the highest relevance score first. In the case of *colour hue*, reasons might be cultural or learned associations of participants with particular hues. For *value*, it appears that the saliency of stimuli varies depending on the contrast to the base map, i.e. simultaneous contrast, and hence fast detection is less predictable and stable. *Transparency* is also the visual variable that shows highest CRR values, in average more than 80%. This suggests that the semantic decoding of geographic relevance with *transparency* works far better than for the visual variables *value* and *colour hue*. The visual variable *value* seems to suffer from ambiguity in semantic understanding and needs to be used with caution for encoding the geographic relevance on mobile maps where space for a legend resolving unambiguity is restricted. In our study, the visual variable *colour hue* performed worst. The traffic light metaphor does not seem to be suitable for encoding geographic relevance and can be easily misinterpreted. This is in line with research doubting the suitability of colour hue for encoding variations of non-categorical data.

Our results show the importance of top-down processes in visual cognition of mobile maps. After receiving prior knowledge, participants had a preconception of what the displayed symbols might stand for and looked at the maps differently. This is reflected in significant differences of TTF and COFS. Since, the second part of the experiment represents a more ecologically valid use case, we can conclude that the good performance of the visual variable *transparency* should be taken into consideration when showing differences of geographic relevance on mobile map displays. However, as common in cartography, the complex and varying background of the geographical base map generates more and less salient regions, which can have a great influence on the perceptual processes.

Future work could include the study of dynamic variables ant testing more than three levels of geographic relevance encoding. Moreover, experiments with more complex tasks and realistic scenarios need to be performed to confirm the results. And finally, a similar experiment could be designed and conducted in an outdoor environment using a mobile eye–tracker.

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