Eye tracking with geographic coordinates: methodology to evaluate interactive cartographic products

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1. Introduction

Empirical research (e.g., User Centred Design or UCD) has repeatedly shown that involving users early on in a product's iterative design has led to major improvements in its usability, but UCD's effective implementation might be still cumbersome (Nivala et al. 2007). One of the main challenges is the balance between ecological validity and experimental control. Data collected in controlled lab studies might be more straightforward to process, but results might not reflect real world use situations. The latter may suffer from hard to control (potentially confounding) variables, unpredictable test conditions, and thus less consistent and comparable study outcomes across participant groups (e.g. Nielsen 1993). This delicate balance can also be found in cartographic user research, for example, when employing the eye tracking methodology to register and analyse users' overt visual behaviour (e.g. Coltekin et al. 2009; Fabrikant et al. 2008; Ooms et al. 2012). In general, current state-of-the-art eye tracking systems have limited automated solutions to deal with the analysis of interactive stimuli. Moreover, users' gaze locations (or Points of Regard, POR), are typically recorded in screen coordinates (e.g., pixel locations in a display) and not in geographic coordinates, which introduces a spatial data analysis challenge when evaluating interactive cartographic products. Nevertheless, the viewed geographic locations might be particularly relevant for a specific spatial decision making task.

Interactive maps in user studies are often approximated by pre-computed animations or by automatically loading a number of subsequent static images (e.g. Fabrikant et al. 2008; Ooms et al. 2012). In doing so, the experimenter introduces a high level of experimental control to facilitate empirical data analysis with dynamic displays. To increase ecological validity, however, participants should be able to execute a task on interactive maps as they would normally do, that is, without restricting their inference making behaviour or the interactivity levels of the tested map display. In the next section, we propose a user-centred evaluation framework based on the eye tracking methodology coupled with user logging to specifically evaluate a wide range of interactive cartographic products.

2. Georeferencing eye movements on interactive maps?

To evaluate interactive cartographic products, it is essential that human-map interactions are tracked. In UCD, user-system interaction logging (e.g., mouse movements, key-stroke analyses, etc.) is often utilized to gather quantitative data from users who execute a task with a product (Haklay & Nivala 2010; Nielsen 1993; Slocum et al. 2001; van Elzakker & Griffin 2013), and this has also been coupled with eye tracking on interactive maps (Coltekin et al. 2009). Depending on the employed eye tracker, low-level user logging might not be readily available, thus additional logging software is typically needed to record detailed user-system interactions (Coltekin et al. 2009). From the range of available loggers, we chose the open source PyHook library to develop custom scripts that *hook into* the computer's operating system, and record detailed user interactions: mouse movements, mouse key presses and releases, and keyboard actions. This desktop-based library works independently from the eye tracker and the digital map application. Consequently, nearly any map product can be evaluated, whether it is a third-party, online map mashup (independent of its API), or any type of (offline) desktop mapping applications.

Logging user actions together with eye movements makes it possible to not only determine when and how user interactions occur, but it also allows to capture where exactly on the map a participant was looking at a certain moment in time. For geographic analyses, this collected data should ideally be in map or geographic coordinates. We detail below how this can be achieved for the panning operation.

(a) (b)

Figure 1. (a) Illustration of the pan operation and (b) different locational reference systems (screen, map, and geographic coordinates)

Panning operations can be conceptualized as a fixed window frame that a user moves over a map without changing the map's viewing scale (red rectangle in Figure 1). This operation is defined by a *mouse key down* (MD) event and consecutive *mouse key up* (MU) event (Figure 1a). By default, the users' POR is registered in screen coordinates, thus relative to the upper left corner of the red rectangles in Figure 1a. As the map scale does not change during the pan event, it is possible to transform the screen coordinates of the POR into the respective map coordinates, relative to the map's centre (blue coordinates in Figure 1b). If the geographic reference system and map projection parameters are known, map coordinates can be transformed into geographic coordinates. Regarding popular online mapping platforms, such as OpenStreetMap, it is the WGS84 locational reference system and a spherical Mercator projection. Using the inverse map projection formula one can re-calculate recorded map pixel locations in the current viewing window to geographic coordinates (green coordinates in Figure 1b).

3. Case study

We employed the OpenStreetMap (OSM) web mapping platform for our proof-of-concept study, and recorded users' POR during three test sessions, each with one of the three most used eye tracking systems: SMI RED250, Tobii T120, and SR Research's EyeLink1000. We followed the identical test protocol. After calibrating participants with the eye tracker, they were asked to press a button to synchronise the internal clock of the eye tracker with the PyHook logger. The screen recording mode was then started to record the entire test session. The same OSM URL was loaded into the Web browser window to make sure that all participants started viewing the map at the same scale and in the same geographic region (i.e. top left image in Figure 2). Participants were then asked to pan to other world regions as illustrated in Figure 2.

Figure 2. Test stimuli and task: pan operation to different world regions

Participants' raw eye movement records (in screen coordinates) were aggregated into fixations using the analysis software associated with each of the used eye trackers. The recorded screen coordinates were transformed into OSM-map coordinates (related to scale level 5), and then to spherical geographical coordinates, as detailed above. Resulting fixation locations were then imported into ArcGIS and visualized over a static world map with OSM's map projection (Figure 3). Visually comparing the target regions (in Figure 2) with the fixated locations in Figure 3, it appears that the fixations recorded with all three systems are indeed located in the expected regions.

Figure 3. Participants' fixations recorded with different eye trackers

However, when synchronizing recorded time stamps from the eye tracker with those from the logging tool, we discovered small deviations (of maximum 10 ms) between the two. This is not uncommon, and can have various reasons (e.g., different internal clock settings, influence of computer processor speed, etc.). Nevertheless, it still acceptable for our purposes, taking into account the minimal eye tracker sampling rate: a gaze location recorded every 8.33ms (i.e., SMI and Tobii).

4. Conclusion

We propose a user-centred evaluation framework for interactive cartographic products using eye tracking coupled with automated user logging that transforms recorded eye movement data from interactive map stimuli (expressed in screen coordinates) to map coordinates and/or spherical geographic coordinates. The resulting eye records coupled with the interaction data (e.g., gaze locations before/after an interaction) can be analysed using different coordinate systems in a GIS (e.g., where on the screen, on the map or in the world was the user looking?). Georeferenced gaze data allows further spatial data processing, using straightforward spatial analysis techniques readily available in off-the-shelf GIS (e.g., buffering, cluster detection, etc.). We believe that our proposed approach will greatly facilitate the empirical study of interactive map use and human decision making with digital maps.

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