# ANALYSING EYE MOVEMENT PATTERNS TO IMPROVE MAP DESIGN


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**ABSTRACT:**

Recently, the use of eye tracking systems has been introduced in the field of cartography and GIS to support the evaluation of the quality of maps towards the user. The quantitative eye movement metrics are related to for example the duration or the number of the fixations which are subsequently (statistically) compared to detect significant differences in map designs or between different user groups. Hence, besides these standard eye movement metrics, other - more spatial - measurements and visual interpretations of the data are more suitable to investigate how users process, store and retrieve information from a (dynamic and/or) interactive map. This information is crucial to get insights in how users construct their cognitive map: e.g. is there a general search pattern on a map and which elements influence this search pattern, how do users orient a map, what is the influence of for example a pan operation. These insights are in turn crucial to be able to construct more effective maps towards the user, since the visualisation of the information on the map can be keyed to the user his cognitive processes. The study focuses on a qualitative and visual approach of the eye movement data resulting from a user study in which 14 participants were tested while working on 20 different dynamic and interactive demo-maps. Since maps are essentially spatial objects, the analysis of these eye movement data is directed towards the locations of the fixations, the visual representation of the scanpaths, clustering and aggregation of the scanpaths. The results from this study show interesting patterns in the search strategies of users on dynamic and interactive maps.


## INTRODUCTION

The goal of this research is to improve the quality of maps towards the user which is related to the design of the map. But how to define ‘a good map design’? The user has to be able to interpret its content in the first place correctly, but also efficiently. If a user can interpret the content of a map correctly, but only after studying the map for a long time, it cannot be considered to have a good design or a good quality towards the user. How users interpret the content of a map, store this information internally and retrieve it later on is related to the structure of their cognitive or mental map (Montello, 2002; Slocum et al., 2001; Downs and Stea, 1977). Therefore, to be able to improve the quality of the map towards the user, insights in the user’s cognitive processes while working with maps are necessary. Consequently, a suitable method is needed to get in touch with the user’s cognitive map during a user study. But maps have a spatial dimension which cannot be neglected when analysing the results of a user study, since it is inherently connected with how users interpret the map’s content.

From the long list of techniques (see Rubin and Chisnell, 2008 and Nielsen, 1993 for an overview), the eye tracking method is considered to be the most suitable method to conduct the user study since the close link between a user’s eye movements and his cognitive processes has been proven multiple times in the past (Duchowski, 2007, Jacob and Karn, 2003, Poole and Ball, 2006, Rayner, 1998). Furthermore, already in the 1970s the feasibility of the tracking technique to study map use was demonstrated (Montello, 2002). Recently, the eye tracking method has also been used to study the design of maps and their usability: their symbology (Brodersen et al., 2001), map animations (Fabrikant et al., 2008), design of the map interface (Coltekin et al., 2009).

But the software packages accompanying the eye tracking devices are not fully suitable to study the spatial dimension of the movement data which is essential to understand how users orientate the map and interpret the map’s content. Eye movement data is essentially not that different from other movement data such as GPS-tracks: a list of $(x,y)$-positions at a certain timestamp $t$. The software package *The Visual Analytics Toolkit* (also known as CommonGIS) was selected to visualize and analyze the scanpaths since its suitability to summarize the eye movement data is already demonstrated in the work of Fabrikant et al. (2008). This package is developed by Andrienko G. and Andrienko A. and its functionalities are described in a number of articles (e.g. Andrienko et al., 2007, Andrienko and Andrienko, 2010). In the next section, the design of the study is described, followed by the results, a discussion and a conclusion.

## STUDY DESIGN

### Apparatus & Participants

The tests were conducted in the Eye Tracking laboratory of the Department of Experimental Psychology, Ghent University. This laboratory is equipped with an Eye Link 1000 device from SR Research (Mississauga, Ontario, Canada) and sample a person's POR (Point of Regard) at a rate of 1,000 Hz (or once every ms). The movements from one eye only are recorded during the tests. The recorded eye movements of 14 subjects were analyzed all of which were students and most of them studied courses at the Faculty of Psychology and Educational Sciences, Ghent University.

### Stimuli & Tasks

Twenty demo-maps were presented to each user in a random order. Each demo-map in the experiment had a simple background – equal on all maps – with point objects (symbolising cities) and associated name labels. On the right, a list with five names was visible. The participants were asked to locate these five names on the map and push a button each time they found a name. By using this task, the user has to perform a visual search on the map. After 50 seconds the map image was translated horizontally over a fixed difference, simulating a pan operation lasting one second. The list with the five names had also changed during this translation: three new names were displayed and two which were already in the former list (but on a different location). Again the user had to locate these five names in the map and push a button when they found one. The eye movements of the participants were recorded during these twenty trials. The combination of the time measurements form the button actions and the location where the user was looking (derived from the eye movement recordings) allows identifying if and which label was found. The visualization of the eye movements gives insights in how users search on the map and if any patterns can be detected in this. An example of a demo-map is depicted in Figure 1: the initial view on top, a view during the translation on the left and the final view on the right.

This task corresponds to an operation which is actually executed rather often by users on dynamic and interactive maps: the user is trying to locate the position of an interest area. To be able to do this, the user has to orientate the map and subsequently scan its content to discover the position of a certain symbol, such as a label. Patterns in these scanpaths give insights in how users interpret and process the content of the map while trying to retrieve information from it and which elements have an influence on these scanpaths. This information in turn allows keying the visualization parameters of maps (such as the position of labels) to the actual cognitive or mental map of the user. Difficulties in the interpretation of the map and thus in locating the labels indicate usability problems which would show in the visualized scanpaths of the subjects, through for example very long and chaotic scanpaths.

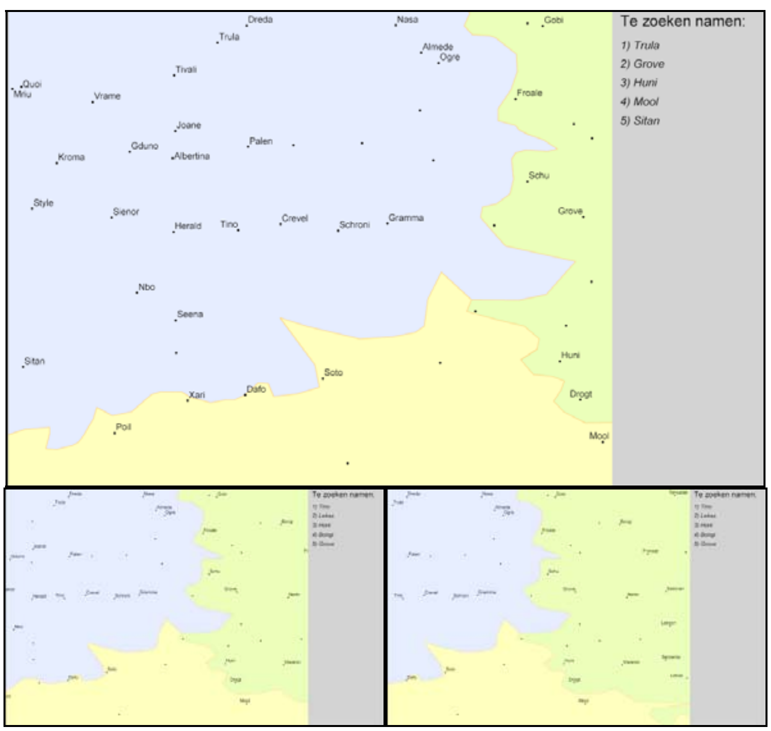



Figure 1. Example of a demo map with on top the initial view,
bottom left a view during the pan-operation and bottom right the final view

## RESULTS & DISCUSSION

As illustrated in Figure 2, the massive amount of eye movement data quickly leads to overcrowded visualizations from which no meaningful conclusions can be drawn. Even when only visualising the eye movements of one person, no patterns can be detected in the movement data due to the massive amount of data gathered with the eye tracking study. The Visual Analytics Toolkit includes a wide range of possibilities to select, aggregate, summarize and visualize the movement data. These analysis and visualization tools are crucial to detect patterns in the eye movements which can provide insights in how users orientate a map.

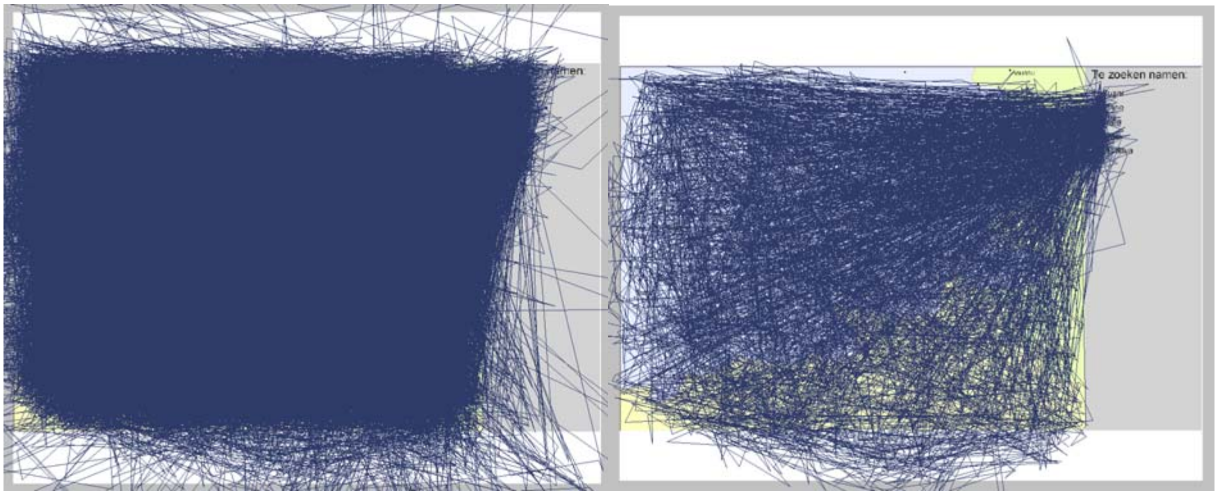
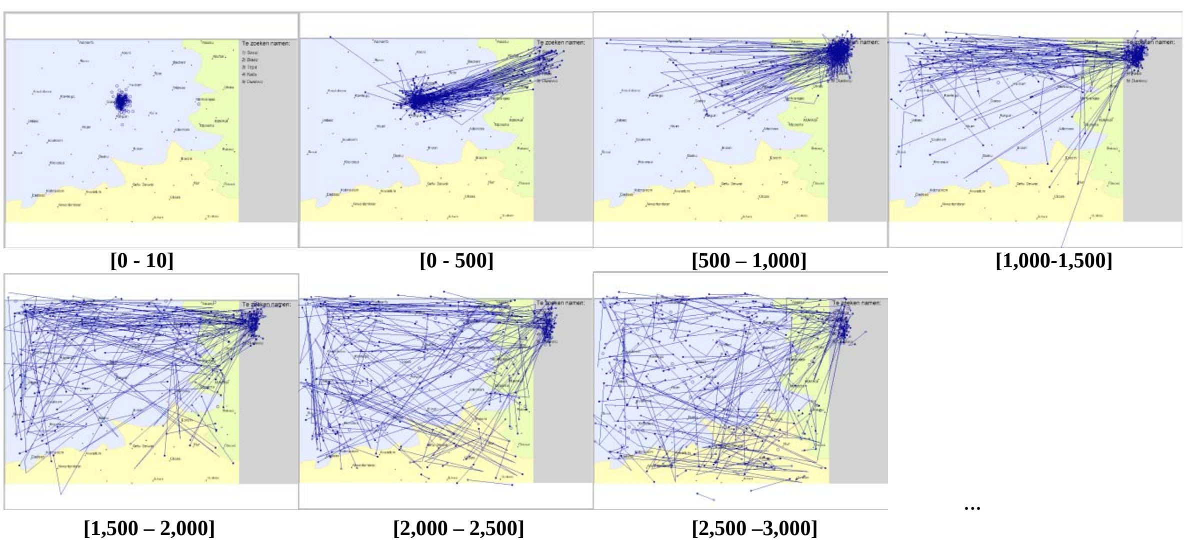
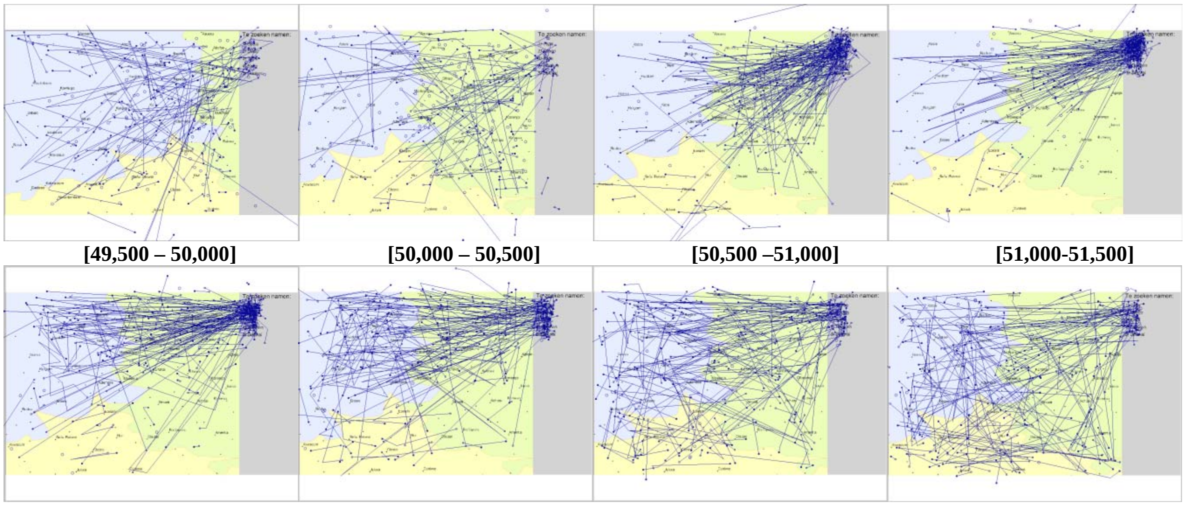



Figure 2. Visualization of the eye movements from all users (left)
or even from only one user cannot be used to detect patterns

One interesting selection technique available in The Visual Analytics Toolkit is the time function which allows defining time intervals; only the movement data which occurred in this interval is visualized. This is an ideal tool to investigate how the scanpaths of the users evolve over time which provides crucial insights in how users orientate the map information and consequently construct their cognitive map. Below in Figure 3, a time series of the scanpaths of all users during all trials is depicted. The first picture depicts the start-situation and every subsequent picture shows the scanpaths in a next interval of 500ms. Picture eight in Figure 3 shows the eye movements in the time interval [49,500ms-50,000ms], that is the time interval right before the simulated pan-operation.





[49,500 – 50,000] [50,000 – 50,500] [50,500 –51,000] [51,000-51,500]

[51,500 – 52,000] [52,000 – 52,500] [52,500 –53,000] [53,000-53,500]

Figure 3. Time series of the user's scanpaths with subsequent intervals of 500ms

The first row in Figure 3 shows that all users start looking at the map near its centre and are subsequently drawn to the list with five names which is read during a certain amount of time. Next, the users start looking for the five names in the top part of the map. Since the eye movements of all participants are visualized, a general pattern in the search behaviour is visible. After 1.5 seconds more users start scanning the lower part of the map, but still a large part is of the eye movements is situated in its upper part. Only after 2500ms, the search pattern of the users is more homogeneously spread over the entire map area, which continues during the remaining intervals. The interval right before the start of the simulated pan-operation also shows this homogeneous distribution of the scanpaths. During the first part of the simulated pan-operation (interval [50,000ms-50,500ms]) this homogeneous distribution continues. This is different during the second part [50,500ms-51,00ms]: the users already start looking at the newly displayed list with names. At this moment, the list with the names has already changed, but the map is not yet completely in its final position. However, most users already start reading this newly displayed list before the end of the simulation. After the simulation, most users are still reading the list with names and some of them already started searching for the names. In this case, the scanpaths are directed more diagonal across the map, but are still mainly situated in the upper part. Another element which can be noticed here is that a larger subset of the scanpaths goes directly to the left part of the map, which was already visible before the simulated interaction. This indicates that the users remember this part of the map and use this information to locate the names in the list in a more efficient way. Two seconds after the end of the simulation, the pattern of the scanpaths starts to look more disperse which also continues until the end of the tests.

## CONCLUSION

To be able to improve the quality of maps, and thus their design, towards the user, it is crucial to get insights in the user's cognitive process while working with the map. The spatial dimension of the maps cannot be neglected in this, since it is closely linked with how users orientate it and interpret its content. Visualising and analysing the eye movements of the users with the Visual Analytic Toolkit allows detecting patterns in the search behaviour of the users while performing a visual search in the map. The preference of nearly all users in the study to start their visual search in the upper part of the map, both in the initial view and after the interaction, is such a pattern which could be detected by visualising the eye movements in subsequent small time intervals. Another patterns detected using this visual analytic method is the more diagonal search strategy which is present after the interaction. This information is important to obtain insights in how the user's cognitive map is constructed and how information is subsequently extracted from it. Keying the designs of maps to the user's mental map ensure the construction of more effective maps towards the user. This is especially important when dealing with dynamic and interactive maps which are found in a wide range of applications on the Internet today.

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