VISUAL ANALYTICS ON EYE MOVEMENT DATA REVEAL SEARCH PATTERNS ON DYNAMIC AND INTERACTIVE MAPS

Abstract: In this paper the results of a visual analytics approach on eye movement data are described which allows detecting underlying patterns in the scanpaths of the user's during a visual search on a map. These patterns give insights in the user his cognitive processes or his mental map while working with interactive maps.

Keywords: map design - mental map - eye tracking - visual analytics

Introduction

A good map design is essential to present the (spatial) information towards the user in an *effective* way. This means that the user has to be able to interpret the information in the first place correctly but also *efficiently*. This is related to how users store and process this spatial information 'internally' which is in turn linked to their cognitive or mental map. (Montello, 2002, Slocum et al., 2001, Downs and Stea, 1977) The ISO 9241-11, *Guidance on Usability*, is an important standard in the field of User Centered Design (UCD). It defines usability in terms of 'quality of use' which can be described by the level of efficiency, effectiveness and satisfaction with which a user achieves a certain goal on a specific system (such as a map). (ISO, 1994, Bevan, 1995)

In this paper, the improvement of the usability maps is described, with a focus on the general design principles of maps. Since this is related to the user's mental map, a suitable method to obtain insights in his cognitive processes while working on a map has to be selected. From the long list of techniques (see Rubin and Chisnell, 2008 and Nielsen, 1993 for an overview), the eye tracking method is chosen 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 maps are essentially spatial objects and the software packages accompanying the eye tracking devices are not fully suitable to study this spatial dimension of the movement data. As a consequence, a visual analytics method is needed to select, aggregate and study the scanpaths in a meaningful way. 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

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.

During the tests, the participants were asked to locate five names on a map, which were listed on the right side of the actual map. The users did not have to remember these five names since the list was visible during the entire test. By using this task, the user has to perform a visual search on the map. This is an operation which actually is executed rather often by users on dynamic and interactive maps such as mash-ups: 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.

Each demo-map in the experiment had a simple background – equal on all maps – with point objects (symbolizing cities) and associated name labels. After 50 seconds the map image was translated horizontally over a fixed difference, simulating a pan operation. The length of this interval was derived from the results of a pilot study conducted earlier. This simulation had a duration of 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. In total, twenty demo-maps were displayed to the participants in a random order. An example of such a demo-map is depicted in Figure 1.

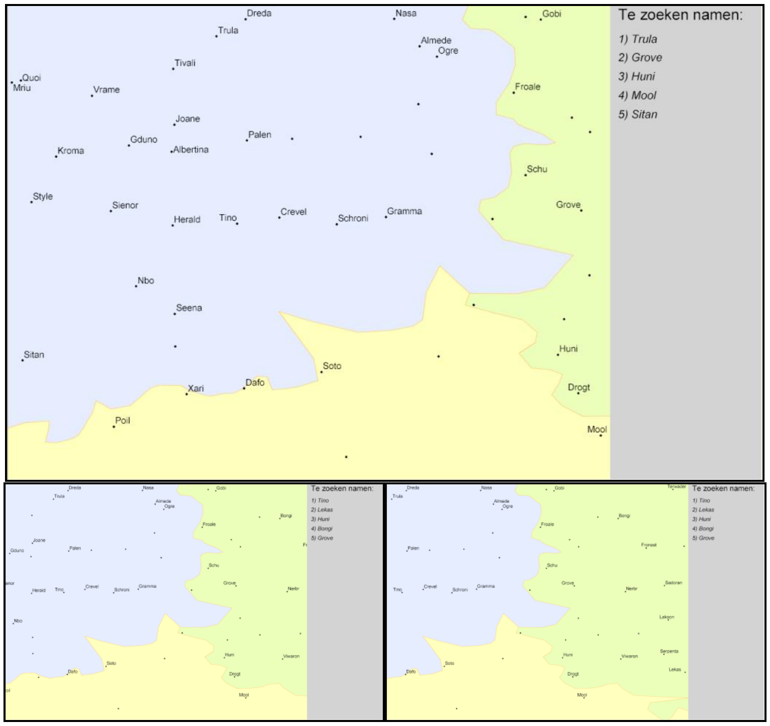


Figure 1: Example of a demo map with on top the initial view,
bottom left a view during the pan-operation and bottom right the final view

During the tests, the eye movements of the participants were recorded. Furthermore, the participants were asked to indicate when they found a label by pushing a button. 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.

Results & Discussion

The massive amount of eye movement data quickly leads to overcrowded visualizations from which no meaningful conclusions can be drawn. This is illustrated in Figure 2. 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.

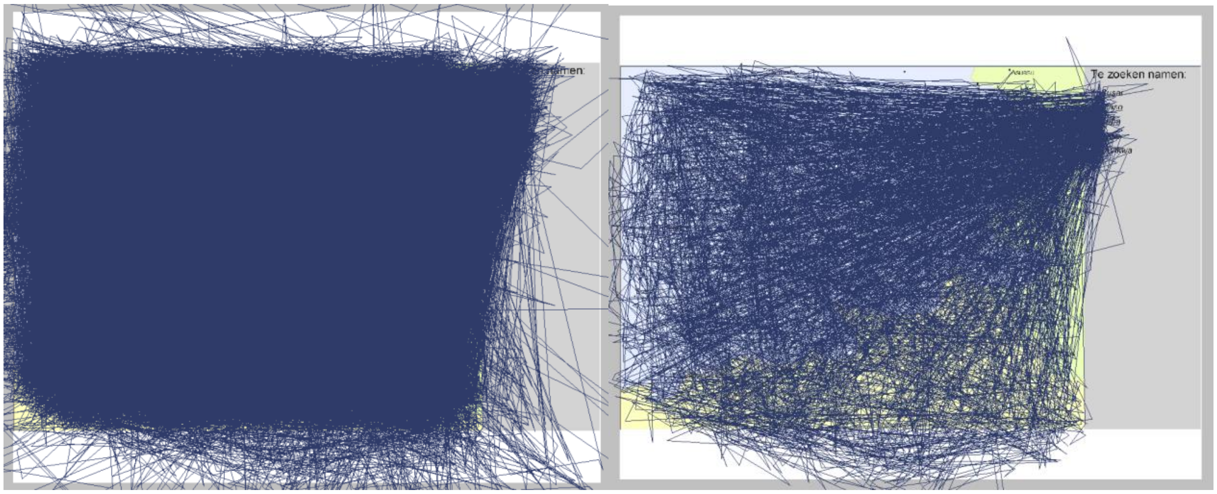
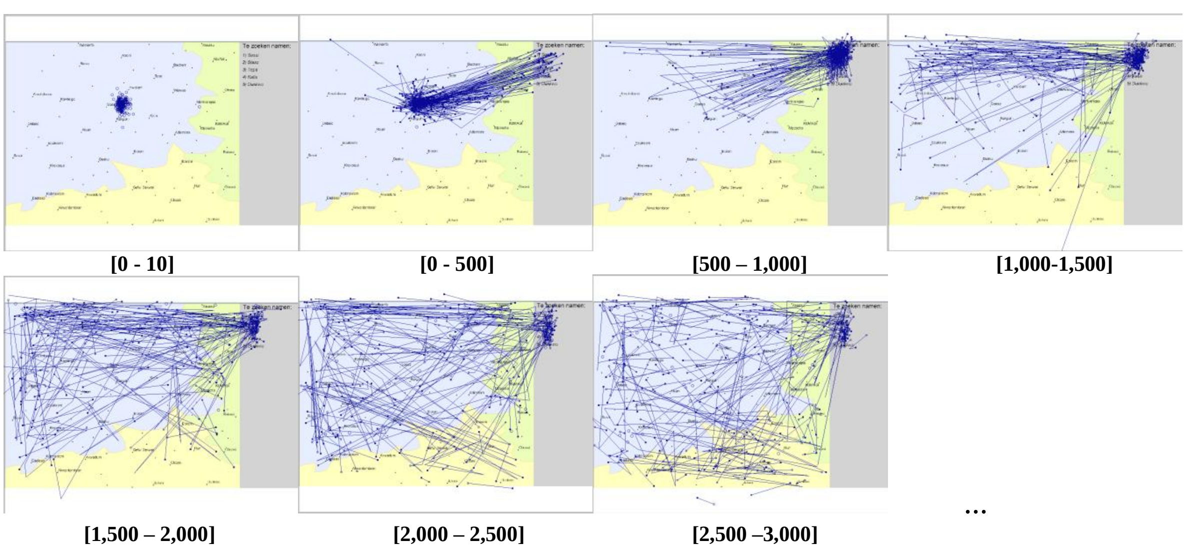


Figure 2: Visualization of the eye movements from all users (left) or even from only one user cannot be used to detect patterns

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.



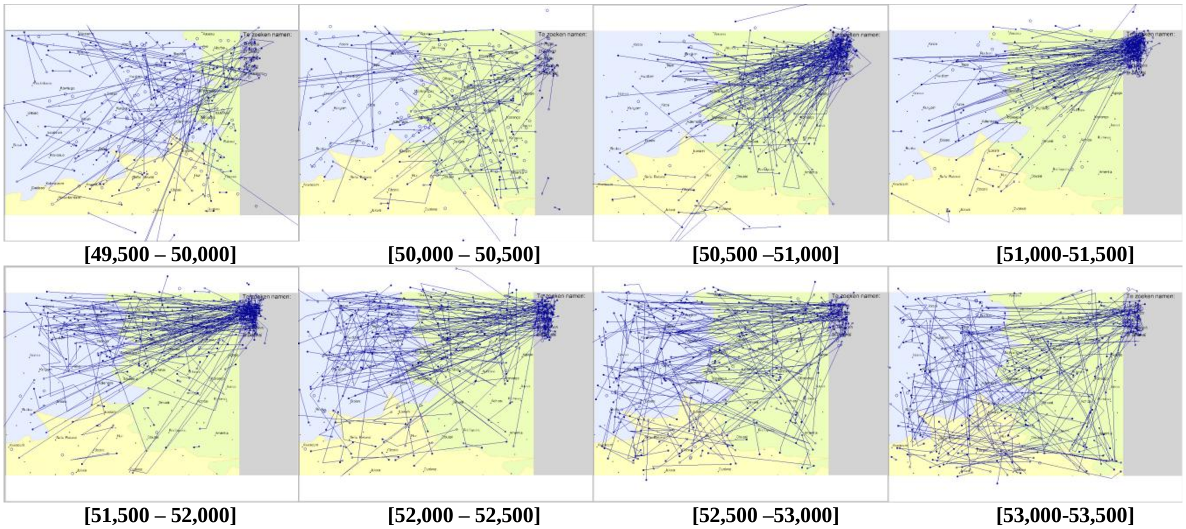


Figure 3: Time series of the user's scanpaths with subsequent intervals of 500ms

The first picture indicates that all users start looking at the map somewhere near its center. Next, nearly all scanpaths are directed towards the list with the five names which is read during a certain amount of time. It also shows that the search pattern of nearly all users starts at the top section of the map and is nearly horizontal. Next, the scanpaths are more distributed over the map, with initially still a large amount of trajectories in the upper section. 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, but this is different during the second part [50,500ms-51,00ms]. In this interval, the users already start looking at the newly displayed list with names. At the end of this interval, 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. 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

The visual analysis of the eye movement data in a specialized software package reveals quite a number of interesting aspects on how users orientate, interpret and store the information presented on maps. This information is essential to get insights in how their cognitive maps are constructed. Keying the designs of maps to the user's mental map ensure the construction of more effective maps towards the user.

References

ANDRIENKO, G., ANDRIENKO, N. & WROBEL, S. (2007) Visual analytics tools for analysis of movement data. *SIGKDD explorations,* 9**,** 38-46.

ANDRIENKO, N. & ANDRIENKO, G. (2010) Spatial Generalization and Aggregation of Massive Movement Data. *IEEE Transactions on visualization and computer graphics*.

BEVAN, N. (1995) Measuring Usability as Quality of Use. *Software Quality Journal,* 4**,** 115-130.

BRODERSEN, L., ANDERSEN, J. H. K. & WEBER, S. (2001) Applying the eye-movement tradcking for the study of map perception and map design. Copenhagen, Denmark, National Survey and Cadastre.

COLTEKIN, A., HEIL, B., GARLANDINI, S. & FABRIKANT, S. I. (2009) Evaluating the effectiveness of interactive map interface designs: a case study integrating usability metrics with eye-movement analysis. *Cartography and Geographic Information Science,* 36**,** 5-17.

DOWNS, R. M. & STEA, D. (1977) *Maps in Minds. Reflection on cognitive mapping,* New York, Harper & Row.

DUCHOWSKI, A. T. (2007) Eye movement analysis. *Eye tracking methodology - Theory and practice.* Springer.

FABRIKANT, S. I., REBICH-HESPANHA, S., ANDRIENKO, N., ANDRIENKO, G. & MONTELLO, D. R. (2008) Novel method to measure inference affordance in static small-multiple map displays representing dynamic processes. *Cartographic Journal,* 45**,** 201-215.

ISO (1994) ISO9241-11: Ergonomic requirements for office work with visual display terminals (VDTs). *Part11: Guidance on usability*.

JACOB, R. & KARN, K. (2003) Eye tracking in human-computer interaction and usability research: Ready to deliver the promises. IN RADACH, R., HYONA, J. & DEUBEL, H. (Eds.) *The Mind's Eye: Cognitive and Applied Aspects of Eye Movement Research.* Amsterdan, Elsevier.

MONTELLO, D. R. (2002) Cognitive map-design research in the twentieth century: theoretical and empirical approaches. *Cartography and Geographic Information Science,* 29**,** 283-304.

NIELSEN, J. (1993) *Usability Engineering,* San Francisco, Morgan Kaufmann.

POOLE, A. & BALL, L. J. (2006) Eye tracking in human computer interaction and usability research: current status and future prospects. IN GHAOUI, C. (Ed.) *Encyclopedia of Human Computer Interaction.* Idea Group.

RAYNER, K. (1998) Eye movement in reading and information processing: 20 years of research. *Psychological Bulletin,* 124**,** 372-422.

RUBIN, J. & CHISNELL, D. (2008) *Handbook of Usability Testing. How to Plan, Design and Conduct Effective Tests,* Indianapolis, Wiley Publishing.

SLOCUM, T. A., BLOK, C., JIANG, B., KOUSSOULAKOU, A., MONTELLO, D. R., FUHRMAN, S. & HEDLEY, N. R. (2001) Cognitive and usability issues in geovisualisation. *Cartography and Geographic Information Science,* 28**,** 61-75.