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EYE - TRACKING METHODS FOR INVESTIGATION OF CARTOGRAPHIC PRINCIPLES

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ABSTRACT

Paper describes possibilities of the utilization of the eye-tracking technology to evaluate user perception and cognition of maps and graphic outputs from Geographical Information Systems.

Eye-tracking is one of the most precise and objective methods of usability studies. The device investigates eye movements and can determine where the monitored person looks. Eye-tracking can help to understand questions concerning user's strategy of the information searching.

Most of modern eye-trackers measure the eye position and gaze direction using remote methods, which rely on the measurement of pupil and corneal reflection from a closely situated infrared light source. The reflected light is recorded with specially designed optical sensor. The information is then analysed to extract gaze position from changes in reflections.

Applied cartography has to follow certain rules to make the map appropriate to the needs of map user. These rules concern the procedure of map composition creation, legend structuring, map complexity optimization etc. The application of cartographic rules can suffer by a considerable degree of subjectivity. Cartographers should evaluate the maps according to user perception and cognition, due to the effort of objectification the map creation processes.

The most frequently used methods of visualization of eye-tracking data are scanpath, which typically evaluates the qualitative characteristics of the observed users behaviour, and HeatMap, used for quantitative evaluation of data obtained by monitoring several users.

On the benefit of the cartography, it is possible to use the analysis of areas of interest (AOI) where different parts of the map (legend, scale, title, specific phenomena in the map, etc.) are evaluated in terms of gaze events. Outputs of these basic methods, mostly expressed by images, are useful for primary orientation in experiment results, but for deeper analyses, statistical approach is necessary.

Several advanced eye-tracking metrics, such as fixation duration, saccade amplitude, saccade/fixation ratio, are used, as well as scanpath comparison, sequence chart analyses and Space-Time-Cube visualization, to confirm the cartographic rules hypotheses. The paper describes all mentioned methods on the example of three case studies within the field of cartography.

Eye-tracking technology was not fully utilized in the cartography or geosciences yet. It is clear that it will have great importance in optimization of cartographic products and visualization of geographic data in the future.

Keywords: cartography, eye-tracking, cartographic rules, evaluation, eye movement

INTRODUCTION

Eye-tracking belongs to the group of evaluation methods, called Usability Studies [11]. The term usability is defined as “the effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments” [9]. Usability can reveal qualities of the product as well as lack of its functionality, which usually arises during the design phase of a product. [8] The assessed product can be an image, web page, text or a map.

Eye-tracking is a technology based on principles of tracking human eye movements while perceiving the visual scene [5]. The main current eye movement measuring method is called the Pupil and Corneal Reflexion method. The principle of this remote (contactless) method is based on measuring the centre of pupil and corneal reflection of direct infrared light beam.

Eye movement is not smooth. Between rapid eye shifts there are delays called fixations. During fixations eyes are relatively firmly fixed on one spot of the perceived image. Between fixations, eyes perform short and extremely rapid movements from place to place, known as saccades. Identifying fixations and saccades is a statistical description of the observed behaviour of the eye. Based on the numerical characteristics of these movements it is possible to determine the relationship of observers toward the pursued image, difficulties in conveying information, the user attention and other parameters of stimulus reading.

At present, eye-tracking is primarily used in marketing, psychology, human-computer interaction and computer interface evaluation. Neither complex map assessment nor map evaluation based on eye-tracking was sufficiently processed in cartography. Marginally devoted to this topic are for example Brodersen et al. [2], Coltekin et al. [3], Fuhrmann et al. [4], Popelka and Brychtova [12] and Alacam with Dalci [1].

CARTOGRAPHICAL PRINCIPLES

Maps have been created and used for centuries as abstractions of the real world, capable of giving an image of the environment which distils its full complexity into an effective graphical representation. Map, as a tool of communication and information transfer, was and still is in the focus of cartographers, who search for best methods of geographical data visualization and evaluate effectiveness and information content of maps.

The map is always the result of several factors, which are applied during the map creation process. The map design is influenced by subjective and objective factors [16]. The objective factors include map theme, aim of the map and technical means of map creation. Subjective factors are represented by the mature of the cartographer (his or her knowledge and experience with application of cartographic means of expression and cartographic software) and individual tendencies, which are reflected by preference of methods or means of geographical data visualization.

Education, personal inclinations of cartographers and thus the resulting map are influenced by the cartographic school, which is dominant for a particular region. Each school provides cartographic principles and rules that are more or less adhered by cartographers. Some of the rules are often not supported by relevant evidence for their application and therefore it is advisable to confirm their validity.

In this paper, three case studies with focus on rules for creating map legends, map composition and labelling are described. Concrete issues are discussed below within specific case studies.

VISUALIZATION AND ANALYSES OF EYE-TRACKING DATA

Results of eye-tracking measurements are presented as a text file containing a timestamp and a number of specifications describing coordinates of the point of regard, the pupil size, the angle of the eye position etc. First of all, it is necessary to classify the data, with a specified algorithm, as fixations and saccades. Then, the data are even visualized in a suitable way, or can be statistically analysed.

There are several basic methods of the eye-tracking data visualization. Holmqvist et al. [7] present the main techniques of gaze data visualization as follows: Scanpath (GazePlot), Attention (Heat) maps and the AOI (Area of Interest) Analysis.

Following chapters will present different possibilities of visualization and eye-tracking measurements on concrete examples from cartography. All examples are based on source data, which are results of several authentic experiments on cartography rules evaluation and which were recorded using the SMI RED 250 remote device.

Case Study 01 - Map Legend Evaluation

Goal of the first case study was to answer several questions related to the map legend. These include for example: Is it necessary to structure the legend or it is necessary to create a legend for all maps? Based on these questions several maps were selected, mostly taken from atlases, both historical and contemporary.

For testing, a total of 16 test subjects were engaged. The respondents were selected from two groups - cartographers (8 respondents - 4 male and 4 female) and non-cartographers (8 respondents - 4 male and 4 female). After the necessary calibration, respondent had unlimited time to read the questions and then 45s for answering the question. The most common way of representing eye-tracking data is to draw a scanpath over the examined stimuli [13]. Holmqvist et al. [7] defines a scanpath as the route of oculomotor events through space within a certain timespan. With use of scanpath, raw data can be displayed, but more often, it is used for fixation and saccades visualization. In this case, fixations are represented as circles (their radius corresponds to their length) and saccades as lines connecting the circles.

Figure 1. Scanpath representing raw data (left) and fixations and saccades (right).

The example of the scanpath is shown as Figure 1. The task was to localize the zinc mines in the map. From the scanpath is evident, that the respondent had to find out the corresponding symbol in the legend first.

Limitation of this method occurs when the number of fixations is too high, and the information represented by scanpath is lost due to the overlaps. There are plenty of solutions of this problem. One of them is neglecting the time component. Data can then be displayed using the attention map which shows only the number of fixations without their order.

Attention maps, usually displayed as HeatMaps or FocusMaps, are tools for visualization of the quantitative characteristics of the user's gaze. From attention map is evident, which part of the stimulus is more attractive for the respondents and which they do not pay attention. Attention maps are very useful for a fast overview on which parts of a document, users are concentrated and which is suitable to analyse deeper.

Example of the attention map (FocusMap) is shown in the Figure 2. FocusMap shows fixation hits related to brightness between darkest (less hits) and normal brightness (more hits). The task was to find out places where flax is grown. The most significant bright spot is located in the area of map legend, where the symbol of flax is situated. Other spots correspond to places with correct answer. The FocusMap was made by aggregating fixations from all 16 respondents.

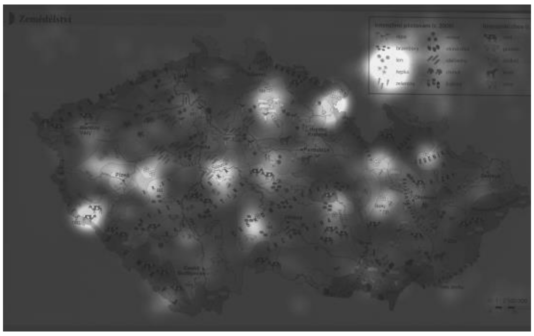

Figure 2. FocusMap made by aggregating fixation hits from 16 respondents.

Data with height fixation overlapping can be effectively visualized without neglecting any component with use of Space-Time-Cube (STC), which is the most important element in Hägerstrand‘s space-time model [6]. In its basic appearance the cube has on its base a representation of the geography (X, Y), while the cube’s height represents time (Z) [10]. As shown in Figure 1, if time does not change, the position of the object or phenomenon is a line perpendicular to the base of the cube. The steeper the line between two vertices, the slower the change in the position of observed object/phenomenon is. (fig. 3a). Today there is software that automatically creates a Space-Time-Cube from the data in the database. It is also important that it is possible to interactively rotate the cube and select the best perspective for data visualization.

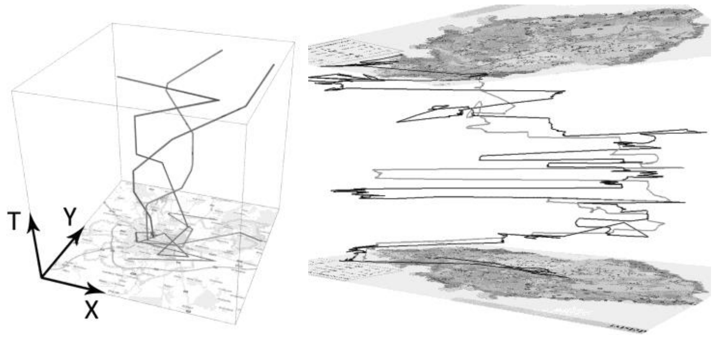

Figure 3. Principle of Space - Time - Cube (left) and its application to eye-tracking data (right).

Figure 3b is Space-Time-Cube visualization of gaze trajectories from two respondents solving the above mentioned task with flax localization. It is visible, that the respondent illustrated by darker colour used the map legend more often than the other one. At the beginning, both trajectories are almost the same; both respondents seek the map legend first.

Case Study 02 - Map Composition Evaluation

Map composition may seem like an insignificant feature, but the correct distribution of composition elements, especially in thematic maps, is very important. The main composition elements include Map title, Map field, Scale bar, Map legend and Imprint [16]. The composition of map depends on the map purpose and group of users who will read a map.

The objective of the case study was to reveal differences in reading of a simple map by two different groups of students. For the case study, visualization method of Sequence Chart was used. For this visualization, creation of Areas of Interest (AOI) is necessary. By indicating and evaluating particular compositional elements as AOI, several characteristics can be find out - e.g. for how long the respondent was observing the given area, in which order he or she visited them etc.

Three different map compositions presented during experiment are displayed in Figure 4. Maps (presented in the first row of Figure 4) were projected in 5s intervals during which the respondents have to observe maps without answering any question. The second raw in the Figure 4 shows a sequence chart for a group of students of geoinformatics and cartography, who have attended several cartography courses. The last row represents data given by cartographic amateurs, students of psychology, zoology etc.

Most geoinformatics students automatically read the title of the map (the darkest colour in Sequence Chart), or rather noted fixations representing it in AOI. Cartographic amateurs did not do so. It is evident especially in the first column, where the stimulus was the “ideal” map composition. In following columns, the composition was not in accordance with cartographic rules. Despite this fact, students of geoinformatics were trying to find the title of the map.

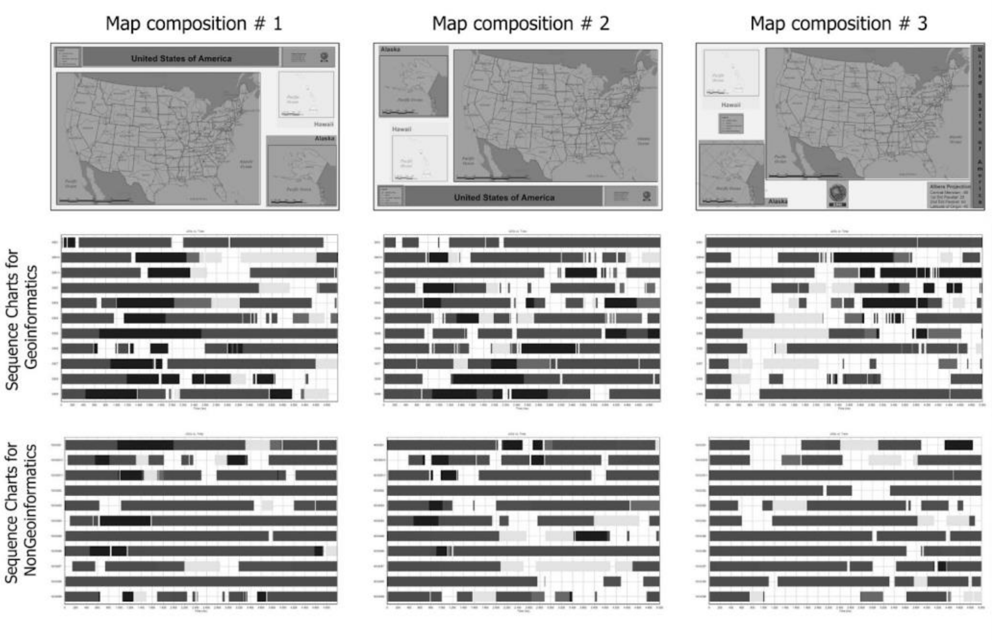

Figure 4. Sequence chart visualization. Sample data of the Esri were used for the creation of stimulus maps. The darkest colour represents the Map Title Area of Interest.

More comprehensive sequence chart evaluation can be done by character string comparison. For each AOI a specific character is assigned and the resulting string represents the order in which AOIs were hit. Two or more character strings can be compared and their similarity can be measured. String edit algorithm determines the number of operations needed to transform one sequence to another - the operations being insertions, deletions and substitutions. The calculated metric will be a measure of how different two sequences are. This method uses the Levenshtein algorithm to produce a string-edit distance between each sequence [15].

Case Study 03 - Map Labelling Evaluation

The aim of the case study was to evaluate the influence of the labelling font-size on the legibility of the map. The experiment was designed as a set of three map stimuli of the same territory. Maps were distinguished from each by font-size of settlements labels. Experiment participants (40 students of cartography and geoinformatics) were asked to find and mark specific settlements using different maps.

The font-size of map labelling was set as the independent. Other independent variables that could affect the readability and speed of finding information (e. g. map content, colour, etc.) in the map were kept identical.

Dependent variables were represented by following metrics derived from the analysis of eye-tracking data: Average fixation duration, Average saccade amplitude, Saccade/fixation ratio and Time to correct answer. All of these dependent variables are important indicators of a particular behaviour of map users in searching for answers (for more details see for example Fuhrmann et al. [4]).

The aim of the experiment was to determine whether the independent variable (the font-size of map labelling) affects the ability of map readers to find the desired information, namely whereas the change of the font-size has an influence on the change of the measured metrics.

Prior to the statistical analysis the data were tested for normality. By the reason that the eye-tracking data did not meet the parametric assumption, the Kruskal-Wallis ANOVA test was used. Kruskal-Wallis test is a nonparametric test used to compare three or more samples. It is used to test the null hypothesis that all populations have identical distribution functions against the alternative hypothesis that at least two of the samples differ only with respect to location (median).

On the significance level $\alpha = 0.05$ the only significant result was proven for time to answer metric (H= 31.28, DF = 2, N=40, P= 1.613e-07); the mean ranks of time to answer are significantly different among the three maps with different font-size.

There were no significant differences in average fixation duration (H= 2.35, DF = 2, N=40, P=0.31), average saccade amplitude (H= 1.33, DF = 2, N=40, P= 0.51) or saccade/fixation duration (H= 3.5, DF = 2, N=40, P= 0.17).

When the obtained value of a Kruskal-Wallis test is significant, it indicates that at least one of the groups is different from at least one of the others. In the case of time to answer metric the post-hoc Kruskal-Wallis multiple comparisons test was used to determine which groups (time to answer on maps with varying font-size) are different with pairwise comparisons adjusted appropriately. Those pairs of groups which have observed differences higher than a critical value are considered statistically different at the given significance level [14].

Significant difference of time to answer data distribution was proven between maps with big and medium font-size (see Table 1).

Table 1. Kruskal-Wallis multiple comparison test of time to answer on maps with varying font-size.

font-size comparison	**observed difference**	**critical difference**
big - medium	15.43590	18.38851
big - small	26.97436	18.38851
medium - small	42.41026	18.38851

CONCLUSION

Up to now, technologies and methods of eye-tracking in cartography were not fully utilized despite their great possibilities in cartography. Thanks to easier (but not easy) access to high-performance eye-trackers, we can expect, in a short time period, more numerous and deeper researches on different aspects of map reading. In the field of map creation, there exist certain short and long-term rules. Many of them are respected without any international convention.

Cartographic research with eye-tracking methods will considerably contribute to argumentation of a high number of empirically based rules and instructions for map creation and the map language will be internationalized. By implication, it will enable geographers to present better results of their researches and studies.

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