Chapter 5

Advanced Map Optimalization Based on Eye-Tracking

Stanislav Popelka, Alzbeta Brychtova, Jan Brus and Vít Voženílek

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/46190

1. Introduction

Mapmakers and cartographers perceive maps differently than the target group of users. In the case map is created by someone else than a professional cartographer the process of making maps suffers by considerable degree of subjectivity. Despite the several-hundred-years effort of objectification of map making process, cartographers sometimes have difficulties to imagine the way how the user will use the map, especially the way of map perception, reading, analysis and interpretation [1]. Cartographers often lack the reasoning for the decision-making in balancing the map design and layout, designing a map symbology, choosing the cartographic method of visualization or level of generalization [2]. For these reasons it is necessary to carry out a research on user perception of maps.

According to Golledge and Stimson [3] the perception is function of a cognition (thinking), which can be understood as a way of encoding, storing and integrating information into existing knowledge. In order to study reading and using maps the perception is very important, because it helps to structure the area depicted on the map.

Several approaches of the research on user perception and evaluation of the applicability and effectiveness of maps exist. The eye-tracking is one of the rarely used. Based on results of eye movements analyses, many questions, that were not yet been discussed in cartography adequately, can be answered. For example, how users obtain information from the map, what is the strategy of map reading, how often users look to the map legend, how easily can be map symbols interpreted, etc. Analyses of maps usability can help in optimizing the map symbology, composition or design, so the new maps can be created in order to respect the specific user's requirements.

The main sensory channel for cognitive processes is vision [4]; therefore the research on map visual perception is necessary

2. Usability studies

The term usability is defined as "the effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments" [5]. Satisfaction quantifies subjective users' impressions dealing with such indicators as operability and learnability of a given task. Efficiency and effectiveness metrics are objective performance measures of speed and accuracy. [6]

Nielsen [7] defines usability as a quality attribute that assesses how are user interfaces easy to use. 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. To be able to derive qualitative or quantitative measures of the user experience (usability), a number of evaluation methods is possible to use. Li et al. [9] mentions these methods of usability evaluation:

- focus group studies,
- interview,
- direct observation,
- think-aloud protocol,
- retrospective think-aloud protocol,
- screen capture,
- eye-tracking.

Each method has its advantages and disadvantages. Frequently a combination of methods is used in the research. For example, see [10, 11, 12].

The method of focus group studies and interview are based on direct contact with the user. They are based on a targeted questioning and recording of discussions and responses of individuals or groups.

The method of direct observation leads to the detection of subject's behaviour in its natural environment without any interference by the observer. For observation various technical utilities, especially recorders, cameras and camcorders, are used. Direct observation sometimes leads to problems in professional ethics, especially when observed people are not acquainted with the fact that they are the subject of observation.

A frequently used method is "Think-Aloud". Its principle lies in the verbalization of the process performed by the user during solving a specific problem. Participating test subjects verbally describe the process of solving specific tasks and also their feelings [13]. This method is very quick and inexpensive, nevertheless, participant is not aware of all cognitive processes, and not all processes can be simply expressed in words. This method is very subjective in the term of observed subjects, who describe their experiences, and also in the term of the evaluation of their response. Detail usage of this method is discussed by Somersen [14]. Similar to the "Think-Aloud" method is a retrospective variant, when the subject describes a workflow after the task is completed.

The screen capture method of usability study was in the field of cartography and GIS used for example in Haklay et al. [15]. They assessed the usability of GIS software using screenshots that users had posted. On these images the windows of application were captured in the middle of the workday and composition of opened toolbars was analysed.

The last mentioned method, which is in the focus of this chapter, uses a device to monitor eye movements. Eye-tracking method can be considered to be objective, because it is not influenced by the opinion of the monitored person [16].

3. Eye-tracking technology

Eye-tracking technology is based on the principles of tracking movements of human eye while perceiving the visual scene. The measurement device used for measuring eye movements is commonly known as eye-tracker. [17]

When users are searching for the information in unknown environment (text articles, web pages, maps etc.), typically two types of processes occur: a perceptual one (the user should locate/notice the target) and a cognitive one (the user cognitively computes the visual input and understands the function of the target). Eye movement analysis provides valuable quantitative and qualitative information on both stages of visual search. [16]

Qualitative information describes the way in which user explores the stimuli. They can reveal areas of maximum interest, disruptive elements and strategy of searching for a specific element. Quantitative information describe the time spent by observing a particular phenomenon, speed of identifying information and several derived gaze data metrics.

3.1. Methods of eye-tracking

In general, there are two types of eye movement monitoring techniques: those that measure the position of the eye relative to the head, and those that measure the orientation of the eye in space, or the “point of regard”. [18]

According to Duchowski [6], methods of eye movement tracking can be categorized into three main groups:

- electrooculography (EOG),
- scleral contact lens/search coil
- remote eye-tracking.

EOG is a method which was popular about 40 years ago. Its principle lies in measuring of skin’s electric potential differences of electrodes placed around the eye. By recording quite small differences in the skin potential around the eye, the position of the eye can be tracked. [19]

The method of scleral contact lens or search coil uses an attachment to the eye, such as a special contact lens with an embedded mirror or magnetic field sensor, and the movement of the attachment is measured with the assumption that it does not slip significantly as the eye rotates. Both mentioned methods measure eye position relative to the head and they are not generally suitable for point of regard measurements.

Currently the most exploited eye movement measurement method is remote eye-tracking, also called the Pupil and Corneal Reflexion method. It relies on the measurement of visible features of eye, e. g. pupil, iris-sclera boundary and corneal reflection of a closely situated direct light source (often infra-red). The reflected light is recorded by a video camera or specially designed optical sensor. The information is then analyzed to extract eye rotation from changes in corneal reflections. The resulting corneal reflexion is also known as "glint" or the 1st Purkinje reflexion (P1) [20].

There are at least four Purkinje images (figure 1). The first Purkinje image (P1) is the reflection from the outer surface of the cornea. The second one (P2) is the reflection from the inner surface of the cornea. The third one (P3) is the reflection from the anterior surface of the lens and the last one (P4) is the reflection from the posterior surface of the lens. [21]

Eye position and gaze direction are estimated using information from an image sensors picking up reflection patterns on the cornea and other information points. By image analysis and mathematics a gaze point on a reference plane can be calculated.

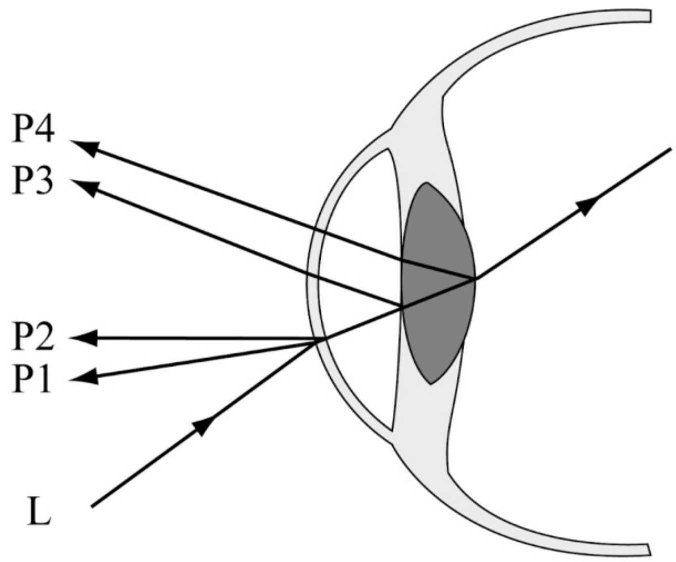

Figure 1. Four Purkinje images - the reflection (L) on different parts of the eye: P1 from the outer surface of the cornea, P2 from the inner surface of the cornea, P3 from the anterior surface of the lens, P4 from the posterior surface of the lens. [22]

3.2. Eye movements and algorithms of their detection

Human eyes can only perceive a limited fraction of the visual world at one point in time. Both eyes together provide a roughly elliptical view of the world which is approximately 200° of visual angle wide and 130° high. [23]

However not all parts of this view are perceived with equal acuity because the retina of the eye has a varying structure and composition. The fovea, part of the retina, is responsible for sharp central vision (also called foveal vision), which is necessary during reading, watching television or movies, driving, and any activity where visual detail is of primary importance. The really high-resolution area covers only about 2° of the visual field. The fovea is surrounded by the parafovea belt and the perifovea outer region [24]. The vision supported by this part of the eye is so called peripheral vision, which in comparison with foveal vision seem to be blurred [25].

Eye movement is not smooth. The eye moves in spurts and rests between each movement. During a fixation, eyes are relatively steadily looking at one spot in the visual scene. In order to achieve the most accurate visual impression of a visual scene, eyes move rapidly in mostly ballistic jumps (i.e., saccades) from one spot to another. Among those rather large saccadic eye movements that an attentive person can easily observe from his or her own experience, there are three other, much shorter eye movements, i.e. tremor, drift, and microsaccades. Their purpose is to avoid saturation effects of the visual receptors on the retina which would lead to fading perception. However, people are unaware of those tiny movements and they can be hardly detected by state-of-the-art unobtrusive eye-trackers. [23]

The analysis of fixations and saccades requires some form of identification that results from the processing of raw eye-movement data. Fixation and saccades identification is an inherently statistical description of observed eye movement behaviours.

It is important to define the exact detection algorithm for eye movement analysis, because different parameterizations of an algorithm might lead to different results [26]. Plenty of algorithms exist, but mostly used are I-VT and I-DT. In the case of the I-VT (Velocity-threshold fixation identification) algorithm, the eye-velocity value is compared to the threshold. If the sampled velocity is smaller than the threshold, the corresponding eye-position is marked as a part of a saccade, otherwise the eye-position sample is assigned to be a part of a fixation. The I-DT (Dispersion-Threshold Identification) algorithm takes into account the close spatial proximity of the eye position points in the eye movement trace. [27]

Based on statistical analysis of fixations, saccades, their mutual relationship and other characteristics, it is possible to identify certain attributes of respondent behaviour.

For example, long average fixation durations can be interpreted in two different ways as either: (1) the user has difficulties extracting information; or (2) the user is more engaged with interpreting a representation [28]. Hence, distinguishing between the two is case specific.

Saccade/Fixation ratio describes the ratio between search activity (represented by the number of the saccades) and processing activity (represented by the number of the fixations). A small saccade/fixation ratio indicates that the user is spending more “cognitive resources” on the task and less cognitive resources on gathering important background information [16].

A large number of saccades indicate a low degree of search efficiency or poor interface layout. User roams from place to place finding no satisfactory answer. Saccadic amplitude together with ScanPath duration and ScanPath length can refer to a strategy of user cognition style, or quality of examined layout [23].

3.3. Eye-tracking device

According to fundamentals of examined problem it is necessary to use a proper eye-tracker. Individual devices differ from one another by precision given by the spatial resolution and accuracy of the point of view. An important parameter is the time resolution, which is expressed in hertz (Hz). Department of Geoinformatics, Palacký University in Olomouc owns static SMI RED 250 Eye-tracker (figure 2) with sample frequency of 120 Hz, so data are recorded approximately every 8 ms.

Device parameters (resolution, mobility) must respect the purpose of the application for which the device is used. Research on sportsmen or driver concentration, or arrangement of goods on the shelves requires a mobile device mounted on the head of the subject (the headset). Evaluation of stimuli on the computer screen or television will rather use the static device.

Figure 2. Laboratory setup with static remote SMI RED 250 eye-tracker at Department of Geoinformatics, Palacký University in Olomouc.

3.4. Current eye-tracking based research on cartographical issues

Anatomy of the human eye is known for hundreds of years, but scientific interest in the processes of visual perception began only during the 19^{th} century [29]. After the Second World War, one of the first measures of gaze direction was done in 1947. The research was focused on the behaviour of military pilots during aircraft landing. It was carried out by analyzing the video with more than 500 000 film frames [30].

With the improvements of the eye-tracking technologies, eye-tracking tools gain their impacts on the usability field and nowadays they are accepted as a tool to improve computer interfaces [11]. Currently eye-tracking is utilizable in many areas of human activity - psychology, medicine, marketing, commercial, etc.

One of the research goals of contemporary cartography is the investigation of perception processing of maps, not only from the commercial point of view, but also in planning, crisis management and rescue operations.

On the one hand, map is very important carrier of information that readers need to assimilate as quickly as possible and undistorted, so cartographers labour for its highest possible accuracy. On the other hand map design and its visual appearance are determinants of user popularity.

In both cases, the key to success is to answer a number of highly debated issues - for example how readers follow the information in the map, in which order and how fast they read the information, which compositional elements they read earliest, how many times they look back to the map legend, which map elements are easy and which difficult to handle, what affects the legibility of the map, etc. These findings can facilitate to evaluate the quality of the map composition, symbology and map content, and thus define the methodology for creating maps that will correspond with requirements of users.

With respect to the investigatory device, maps evaluation using eye-tracking technology is available both for analog maps and the digital cartographic outputs.

One of the first publications focused on the application of eye-tracking methods in cartography is Eye Movement Studies in Cartography and Related Fields [29], in which the author summarizes the results of various studies in the late 80's of the 20th century. It deals with the general knowledge of tracking of the human eye, studies on evaluation of specific graphic outputs, emphasizing the impossibility to generalize the findings in the behalf of dissimilar studies. He described several universal conclusions and highlighted the importance of distinguishing between user groups according to their age and education.

It is possible to separate the evaluation of information content of maps from the map design. However complex evaluation is more logical, because the information value of maps (e. g. content) can be increased or degraded by technical or artistic design.

An example of a complex evaluation of maps was presented by Alacam and Dalci [11], who compared four map portals (Google Maps, Yahoo Maps, Live Search Maps and MapQuest). Results of eye-tracking experiment revealed considerable variance in the strategy of solving particular quest in different map portals environment. Basic assumption of this study was that the lower the average duration of fixation, the more intuitive the environment. It was found, that users average fixation duration at the Google Map stimuli is statistically significantly lower, than in the case of other evaluated portals.

Coltekin et al. [31] in their research deal with the evaluation of user interface of cartographic software. Test subjects were ask to create a complex map in two different map applications. The study was designed as a between-subject experiment and eye movement analysis was coupled with traditional usability metrics to identify possible design issues. Initial analyses included statistical tests for satisfaction, effectiveness (accuracy of response), and efficiency (response speed).

In a different study the same authors [32] deal with a generic evaluation approach combining theory and data-driven methods based on sequence similarity analysis. The approach systematically studies users' visual interaction strategies when using highly interactive map interfaces. The result was that the participants generally follow a sequence that agrees with the hypothetical sequence representing user's strategies.

Another application of eye-tracking in cartography appears in the study of Opach and Nossum [33] where authors have explored the suitability of eye-tracking on two different semistatic and traditional cartographic animations of temperature and weather. Contrary to the author's previous web based experiment, analysis of the eye-tracking data revealed that the viewing behaviour were surprisingly similar. Three of the metrics used (fixation counts, observation length and time to first fixation) indicated very similar viewing strategies and behaviour during viewing different kind of cartography animations.

Fuhrman, Tamir and Komogortsev [34] have dealt with an assumption that three-dimensional topographic maps provide more effective route planning, navigation, orientation, and way-finding results than traditional two-dimensional representations. The eye-tracking metrics analysis indicates with a high statistical level of confidence that three-dimensional holographic maps enable more efficient route planning.

Popelka and Brychtova [35] used eye-tracking together with questionnaire investigation for evaluation user's attitudes toward interactive methods of virtual geovisualisation of changes in the city built-up area. Five approaches of visualization were assessed - textual description of changes, comparison of historical and recent pictures or photos, overlaying historical maps over the orthophoto, enhanced visualization of historical map in large scale using the third dimension and photorealistic 3D models of the same area in different ages.

Technologies and methods of eye-tracking have not yet been fully utilized in cartography, even though the possibilities are wide. Cartographic research in the field of eye-tracking currently focuses explicitly on improving the user quality of maps. Future potential expansion of eye-tracking technology can be seen in the activity of the International Cartographic Association, especially the Commission on Use and User Issues [36] and the newly established Commission on Cognitive Issues in Geographic Information Visualization [37].

4. Methods of eye-tracking data visualization

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 (see chapter Eye movements and algorithms of their detection). 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. [20] 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. In this way, methods of eye-tracking will be shown. All examples are based on source data, which are results of several authentic experiments on cartography rules evaluation.

All presented case studies were performed using the SMI RED 250 remote device with the sampling frequency of 120 Hz. Eye position was measured every 8ms.

Respondents were chosen from university students of Geoinformatics and Cartography and also from other studying fields which are not related to cartography.

4.1. ScanPath

ScanPath is defined as a route of oculomotor events through space within a certain time-span [20]. Thanks to ScanPath, it is possible to display raw data as well as calculated fixations and saccades. Circles of different sizes represent fixations (their radius corresponds with their length) and lines which connect the circles represent saccades [38].

When a larger amount of data is displayed, this method becomes restraining. Overlapping parts of individual fixations cause that it is not possible to identify their number visually. Figure 3 shows an example of a ScanPath. Respondents were asked to find the highest peak on one of the maps. The aim of this experiment was to compare two types of visualization - perspective 3D display and a classical orthogonal map supplemented with the shading. Raw data are displayed on the left of the picture, fixations and saccades on the right. From both pictures, it is evident that this particular respondent preferred the three-dimensional visualization. His answer is displayed by a red dot which represents the mouse-click.

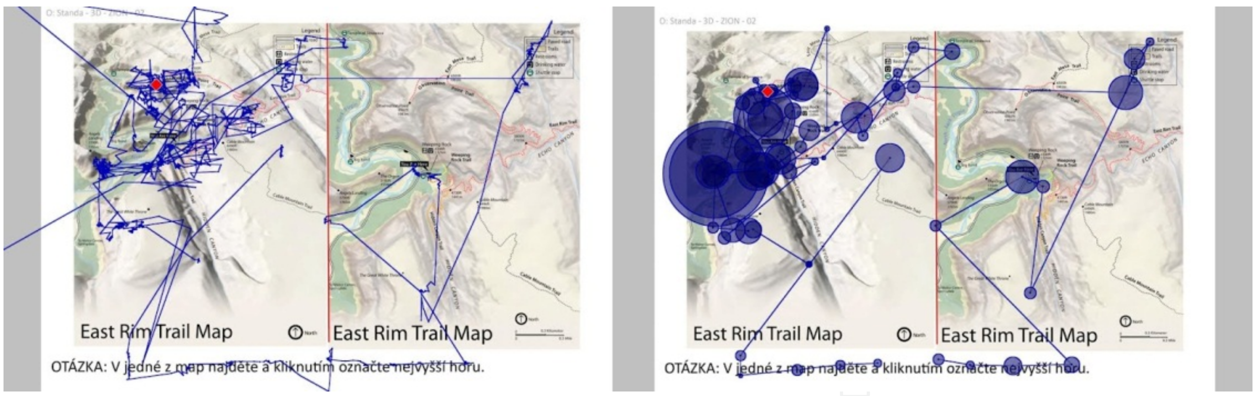

Figure 3. ScanPath showing raw data (left) and fixation and saccades (right)

4.2. ScanPath comparison

There is a great need for robust and general method for ScanPath comparison existing in many fields of eye-tracking research [39]. Privitera and Stark [40] introduced ScanPath comparison based on string editing. Fixations are replaced with characters standing for the AOI's they hit and the ScanPath is represented as character string. It is one of the first methods comparing not only the loci of fixations, but also their order. The principle of this method is the transformation of two-dimensional data (X, Y coordinates of fixations) to one-dimensional data (character string). Each ScanPath is recorded as a string of letters where each letter corresponds to the area of a current fixation location.

Two or more character strings are then compared and their similarity is measured. Defined by an optimization algorithm, string editing assigns a unit value to three different character operations: deletion, insertion, and substitution. Characters are then manipulated in order to transform one string into another and character manipulation values are tabulated [41]. 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 [42]. Example of the Levenshtein distance measure is in the figure 4. Character string comparison methods are widely used in bioinformatics to align DNA and protein sequences.

Similarity discovery

Search within sequences S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
S1	-	11.0	13.0	13.0	13.0	15.0	12.0	13.0	13.0	13.0	14.0
S2	11.0	-	8.0	8.0	8.0	11.0	10.0	10.0	11.0	6.0	10.0
S3	13.0	8.0	-	8.0	5.0	8.0	9.0	7.0	9.0	7.0	7.0
S4	13.0	8.0	8.0	-	8.0	9.0	6.0	8.0	9.0	8.0	9.0
S5	13.0	8.0	5.0	8.0	-	7.0	9.0	6.0	9.0	9.0	6.0
S6	15.0	11.0	8.0	9.0	7.0	-	9.0	9.0	12.0	10.0	9.0
S7	12.0	10.0	9.0	6.0	9.0	9.0	-	10.0	10.0	8.0	10.0
S8	13.0	10.0	7.0	8.0	6.0	9.0	10.0	-	9.0	7.0	8.0
S9	13.0	11.0	9.0	9.0	9.0	12.0	10.0	9.0	-	12.0	10.0
S10	13.0	6.0	7.0	8.0	9.0	10.0	8.0	7.0	12.0	-	8.0
S11	14.0	10.0	7.0	9.0	6.0	9.0	10.0	8.0	10.0	8.0	-

Scores shown are the Levenshtein distance between collapsed sequences.
This is a **distance** measure

Figure 4. Result of the Levenshtein distance measure between group of eleven geoinformatics while observing a map. Gridded AOI with grid of 5*5 cells was used

Depending on specific tasks, it is important to distinguish between gridded AOI and semantic AOI approaches. When using the Gridded AOI, stimulus is split into areas of equal size (rectangles) with no relation to semantics. The second approach, Semantic AOI uses the Area of Interest which corresponds to specific areas in stimuli. In cartography, Semantic AOI is generally more advantageous because it corresponds to map composition elements like title, legend, etc.

4.3. Attention maps

Attention maps, also called HeatMaps, are used for visualization of quantitative characteristics of the user's gaze. Thanks to attention maps, it is possible to identify to which area user pay attention and which are rather neglected. In eye-tracking, HeatMaps enable the creation of a brief summary of areas which are in the spotlight and so they are needed to be analyzed more thoroughly. Except of the function of visualization, they might be used as a background for AOI creation. When plotting AOI around a small object, fixations of some of the respondents could be noted outside the created AOI because of inaccurate measurement or calibration deflection. By means of HeatMaps, it is possible to get an overview of possible measurement inaccuracies and so to adapt the Area of Interest.

HeatMaps produced by SMI software BeGaze are created in two steps. The software first scales each pixel in proportion to the durations of all fixations landing on it. Typically, this results in a very sparse "Fixation Hit Map", since only a small proportion of the pixels have been "hit". In next step, the hit map is convolved with a Gaussian kernel with certain width. A wider kernel gives a smoother, less pointy appearance to the attention map [20].

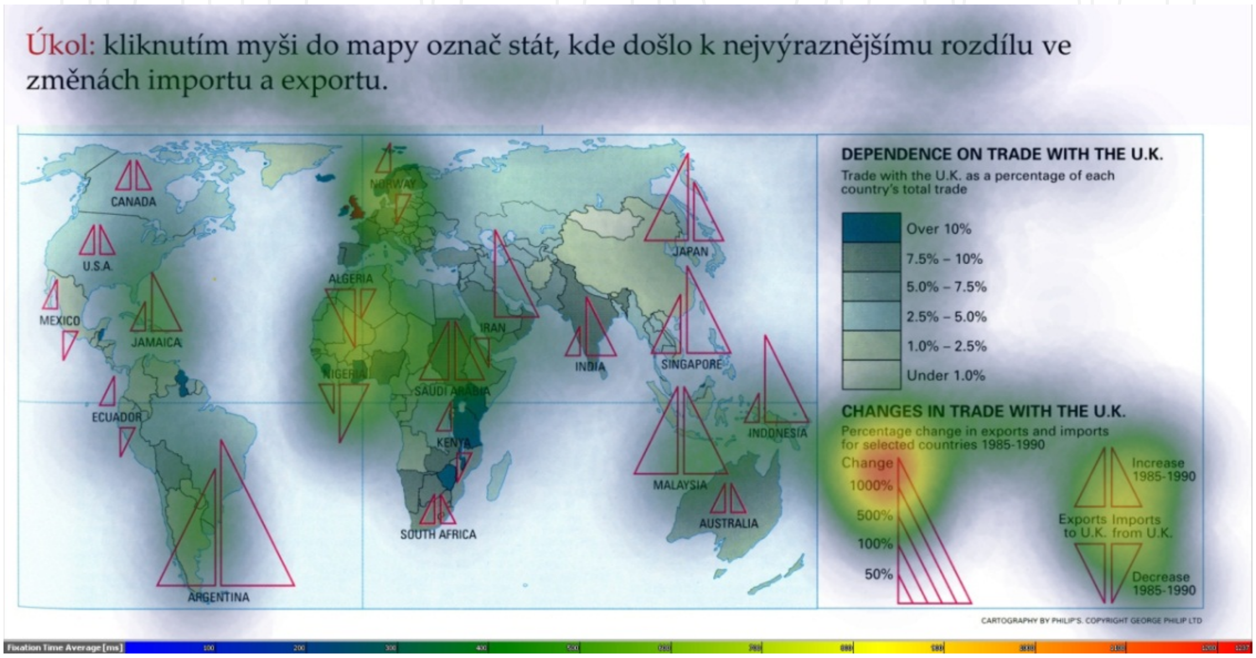

Figure 5. HeatMap created from fixations of seven respondents

4.4. Area of Interest

Areas of Interest (AOI) are regions in the stimulus which the researcher is interested in. The most important AOI metric is the dwell time defined as one visit in AOI, from entry to the exit. The dwell has its own duration, the starting point, the ending point, dispersion etc. In several ways, it is similar to a fixation, but it is of much larger entity, both in space and time [20]. It is also possible to follow the order in which the respondent looked at particular areas or the transition, the movement from one AOI to another etc.

In cartography the Areas of Interest analysis can be used advantageously. AOI analyses are based on evaluation of concrete parts of a map (legend, scale, title, specific phenomena in the map, etc.). When evaluating influence of a composition on the map reading, the application of AOI is very useful. 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 visited them etc.

The results can be visualized with use of the Sequence Chart, which displays observed areas in different colours on a timeline. Figure 6 shows results of an experiment, whose objective was to reveal differences in reading of a simple map by a group of students of cartography and cartography amateurs. Three different map compositions are displayed in figure 6. Maps (presented in the first row of figure 6) were projected in 5s intervals during which the respondents have to observe maps without answering any question. The second raw in the Figure 6 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.

Each stimulus was preceded by a short cross used to locate beginning of all trajectories at the same place (in the middle of the picture). That is why the AOI representing the map field is always pictured in first 500 ms. After this time; most geoinformatics students automatically read the title of the map, 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 [43]. 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.

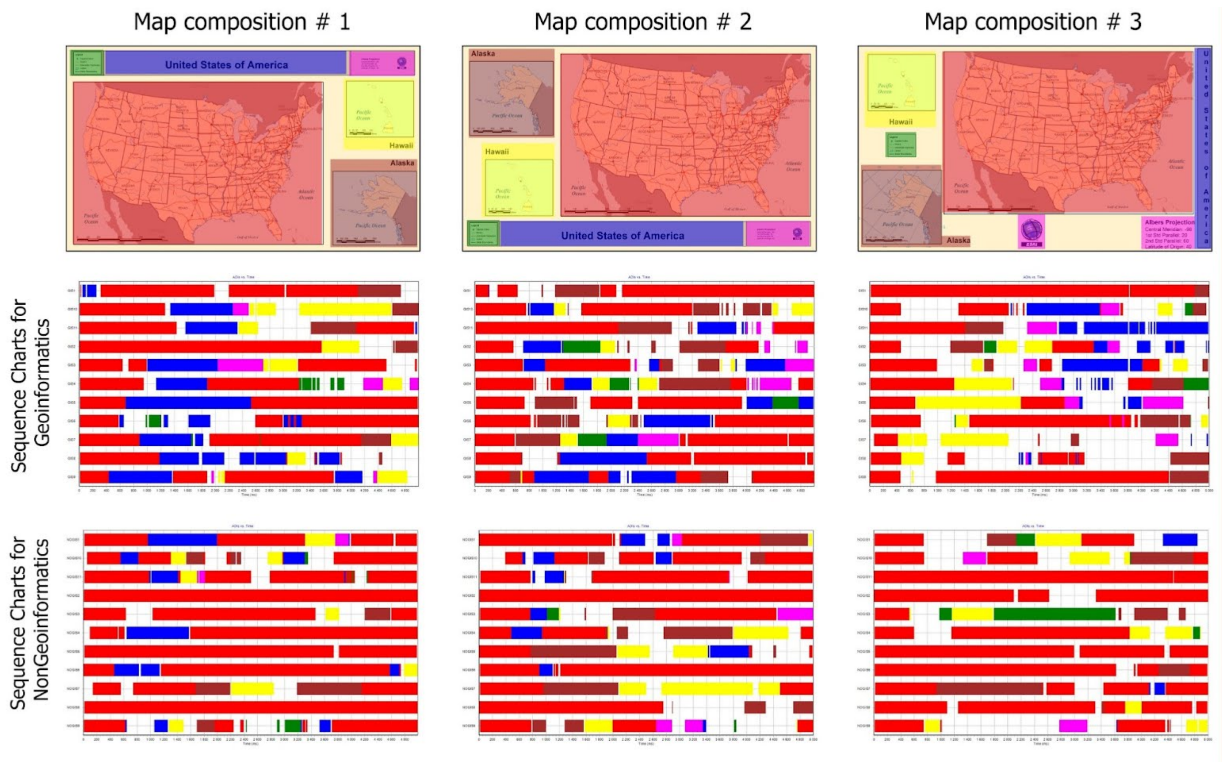

Figure 6. Sequence chart visualization. Sample data of the Esri were used for the creation of stimulus maps

The Sequence Chart is illustrative and easy to interpret, but it is necessary to evaluate the data by statistical approach.

The objective of the statistical hypotheses testing is to evaluate the data gained from experiments and the suitability of the purpose given before the testing. Statistical hypothesis is a certain purpose about the distribution of accidental quantities of a basic file.

In statistics, the result is called statistically significant when it is unlikely to have occurred by chance alone, according to a pre-determined threshold probability, the significance level. Critical tests of this kind may be called tests of significance. When such tests are available, we can say whether the second sample is/ is not significantly different from the first one [44].

From a more detailed evaluation of different types of basic eye movements (fixations and saccades), or gaze data metrics such as dwell time, it is possible to deduce a series of numeral metrics suitable for other statistical testing.

Different composition perception with two different groups of map users (experienced cartographers and non-cartographers) was verified by the testing of measured results by a two sample t-test, which is a method of mathematical statistics making possible to verify the null hypothesis that the means of two normally distributed populations are equal.

Differences of the mean dwell time of two groups of users were tested on particular Areas of Interest of the map list - title of the map, the map, the legend, the imprint and secondary maps. A zero hypothesis H0 was tested: mean values of particular choices are the same. Concrete results are illustrated in table 1.

	t	df	p-value	alpha	mean of carto [ms]	mean of non-carto [ms]	statement
Main map	-2,2189	33,374	0,0334	0,05	2375,58	3080,11	Rejecting H0
Map heading	3,7546	51,501	0,0004	0,05	631,27	230,78	Rejecting H0
Additive map 2	0,0963	36,715	0,9238	0,05	387,84	376,47	Fail to reject H0
Additive map 1	-0,1874	40,321	0,8523	0,05	260,59	284,08	Fail to reject H0
Masthead	1,1999	36,275	0,2380	0,05	127,27	57,57	Fail to reject H0
Map legend	0,2211	45,702	0,8260	0,05	99,50	84,33	Fail to reject H0

Table 1. Results of two sample t - test of dwell time on particular compositional map elements of two different user groups.

By comparing the mean dwell time in particular AOI it is evident that both groups spent most time on the main map field. Extremely long time was noticed at students of cartography in AOI covering the map title. The same AOI was on the 4th position with non-cartographers.

The t-test result disproved the zero-hypothesis saying that the values of the mean dwell time were the same with AOI map heading and the main map field. The visit rate of the main map field was significantly higher with non-cartographers. On the contrary, the map title visit rate was higher with cartographers. There was no difference of the dwell time statistically proved with other observed AOI.

4.5. Space-Time-Cube

Data sets created as a result of the eye-tracking are often very large, which limits their visualization possibilities by means of methods mentioned above. When displaying larger data sets with the ScanPath visualization, overlapping parts are created and the follow-up interpretation of results is not possible. The cause of this problem is displaying of three-dimensional data (X, Y, time) into two-dimensional space (X, Y).

With relatively smaller data sets, it is possible to use colours to differentiate fixations according to their order. During the visualization, transparency can be used to identify overlapping fixations.

Another possible solution is to neglect the time. Two dimensional data (X, Y) can be then displayed by means of HeatMap method which displays only the number of fixations, without their order. However, the loss of the information can make the analysis of results impossible in many cases.

Thanks to Space-Time-Cube (STC) which is the most important element of the Hägerstrand time-space model, the data can be effectively visualized without neglecting any of the data files [45].

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) [46]. As it is evident from figure 7, if the location of the observed object or phenomenon does not change in time, the line is always 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. Today there are softwares 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 analysis.

By means of Space-Time-Cube, it is possible to portray any space-time data. These might be for example data recorded by a GPS device, statistic data containing information about location and time, or data detected with eye-tracking.

In this case, coordinates X and Y describe the distribution of fixations in space, and time is described by the axis Z. Thanks to Space-Time-Cube it is possible to reveal different behaviour of particular users. On the other hand, ScanPath cannot identify in which direction the user moved when reading the picture. Up to now, application of Space-Time-Cube with analysis of eye-tracking data was examined only by [9, 47, 48].

Space-Time-Cube visualization is presented in this chapter on testing the user's perception of the map legend. Respondents were given the task to mark flax growing areas on the map. The aim of the test was to find out the proportion of respondents (%), which use the map legend to fulfil the task. Trajectories of eye movements of two respondents are displayed in figure 8. It is evident that during the first two second of solving the task, the respondents followed almost the same gaze trajectories. One of the first fixations of both respondents are localised in the legend. Then, the respondents tried to answer the given question and started to explore the map.

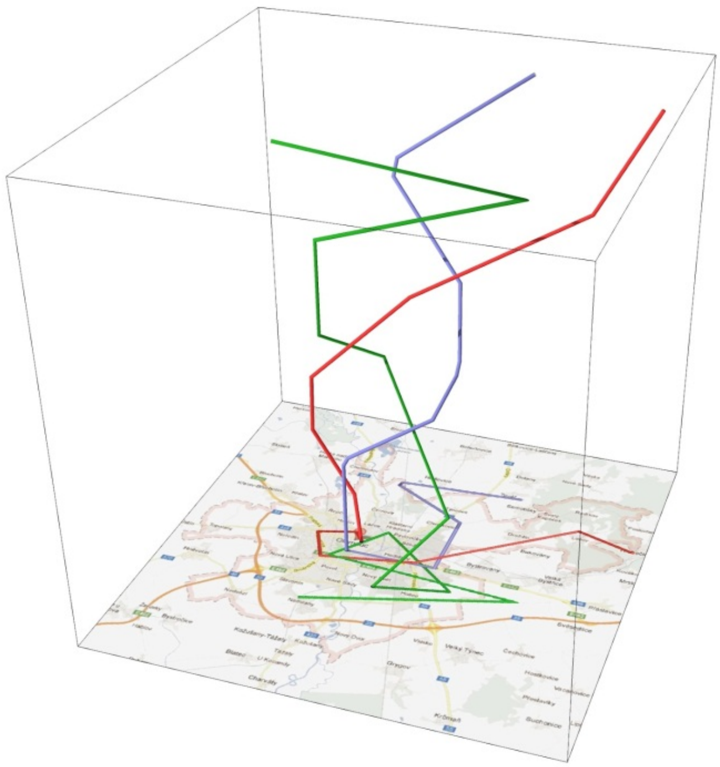

Figure 7. Time-space data displayed by means of Space-Time-Cube.

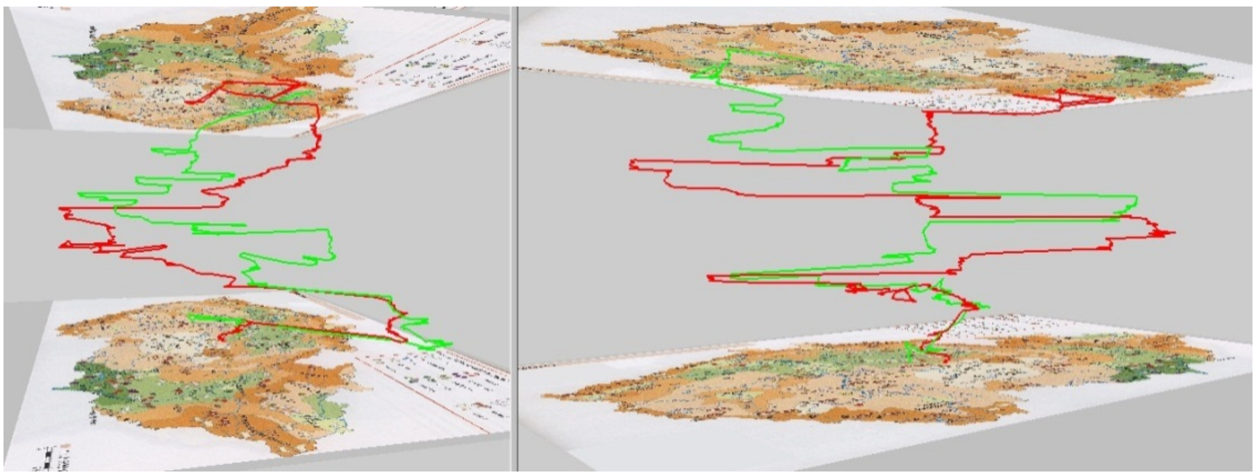

Figure 8. Use of Space-Time-Cube visualization for investigation of ScanPaths from two respondents

5. Conclusion and prospects

Up to now, technologies and methods of eye-tracking in cartography were not fully utilized despite their great possibilities in cartography. A cartographical research in the field of eye-tracking recently focuses on the improvement of the user quality of a map, particularly on the map composition improvement. However, there is a question how to define the user quality of a map or a "good" map composition. In the main, the user has to be able to interpret the content of the map correctly and accurately. A correct but a too long interpretation of a map cannot be considered as a sign of high user quality of the map. A method of the map content interpretation or the way of internal recording and later recalling of the information are related to its structure of cognitive and mental maps [49, 50, 51]. That is why the improvement of the user quality of a map is considered necessary if we want to perceive into cognitive processes going on during work with maps. In this field, eye-tracking can enable the user to do a research of cognitive maps. Nevertheless, it is necessary to respect the fact that maps have its own special dimension which cannot be neglected during the research because it is essentially connected with the user's map-content interpretation.

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, for example a blue colour used for waters [52].

High initial investments on high quality equipment and a non-existence of a single methodology for preparing and evaluation of tests limit the implementation of the described technology in cartography research. It is also necessary to cooperate with a professional psychologist.

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.

Author details

Stanislav Popelka, Alzbeta Brychtova, Jan Brus* and Vít Voženílek
Department of Geoinformatics, Palacký University in Olomouc, Czech Republic

Acknowledgement

The chapter has been completed within the project CZ.1.07/2.4.00/31.0010 Supporting the creation of a national network of new generation of Cartography – NeoCartoLink which is co-financed from European Social Fund and State financial resources of the Czech Republic and the project The small format photography in the study of the effect of heterogeneity on the surface of habitats of the Palacky University (Integral Grant Agency, project no. PrF_2012_007)."

* Corresponding Author

6. References

[1] Muehrcke, P. C. et al. (2009). Map Use: Reading and Analysis. Redlands, ESRI, 6th edition, 528 pp.

[2] Voženílek, V. (2005). Cartography for GIS: Geovisualization and Map Communication. Univerzita Palackého v Olomouci, 142 pp.

[3] Golledge, R. G., Stimson, R. J. (1997). Spatial behavior: a geographic perspective. New York: Guilford Press, 620 pp.

[4] Board, C., Taylor, R. M. (1977). Perception and Maps: Human Factors in Map Design and Interpretation. In Transactions of the Institute of British Geographers, New Series, 2, 1, pp. 19-36.

[5] ISO 9241-11. Ergonomic requirements for office work with visual display terminals (VDTs) - Part 11: Guidance on usability. International Organization for Standardization, 1997. 22 pp.

[6] Duchowski, A. T. (2007). Eye tracking Methodology, Theory and Practice. Springer - Verlag London Limited, 2007, 321 pp.

[7] Nielsen, J. (2003). Usability 101: Introduction to Usability. Alertbox: Current Issues in Web Usability, [online]: < http://www.useit.com/alertbox/20030825.html>

[8] Hub, M., Víšek, O., Sedlák, P. (2011) Heuristic Evaluation of Geoweb: Case Study. Europan Computing Conference. Proceedings of the European Computing Conference (ECC ‘11) s. 142-146. ISBN: 978-960-474-297-4.

[9] Li, X., Coltekin, A. A., Kraak, M. J. (2010). Visual Exploration of Eye Movement Data Using the Space-Time-Cube. In Geographic Information Science, Lecture Notes in Computer Science, Vol. 6292/2010, pp. 295-309.

[10] Cutrell, E., Guan, Z. (2007). What are you looking for? An eye-tracking study of information usage in web search. In Proceedings of the SIGCHI conference on Human factors in computing systems, San Jose, California, USA, 10 pp.

[11] Alacam, O., Dalci, M. (2009). A Usability Study of WebMaps with Eye Tracking Tool. In Human-Computer Interaction, New Trends, Lecture Notes in Computer Science, Vol. 5610/2009, pp. 12-21.

[12] Sedlák, P., Hub, M., Komárková, J., Víšek, T. (2010) Nový přístup k testování a hodnocení kvality map. Geodetický a kartografický obzor. 56/98, 9, Praha, pp. 182-188.

[13] Dykes, J., Maceachren, A. M., Kraak, M. J. (2005). Exploring geovisualization. Elsevier Ltd., UK, 705 pp.

[14] Somersen, M. W. et al. (1994). Think aloud method: A practical guide to modelling cognitive processes. London, Academic Press. University of Amsterdam, Department of Social Science Informatics, 205 pp.

[15] Haklay Mordechai, Zafiri Antigoni (2008): Usability Engineering for GIS: Learning from a Screenshot. In The Cartographic Journal, Vol. 45, No. 2, pp. 87–97.

[16] Goldberg, J. H., Kotval, X. P. (1999). Computer interface evaluation using eye movements: methods and constructs. In International Journal of Industrial Ergonomics, Vol. 24, pp. 631-645.

[17] Gienko, G., Levine, E. (2005). Eye-tracking and augmented photogrammetric technologies. In Proceedings ASPRS 2005 Annual Conference, Baltimore, Maryland, 8 pp.

[18] Young, L. R. And Sheena, D. (1975) Eye-movement measurement techniques. American Psychologist 30, 315-330

[19] Mohamed, A. O. Da Silva, M. P., Courboulay, V. (2007). A History of eye gaze tracking. Computer Vision and Pattern Recognition, 16 pp., [online]: <http://hal.archives-ouvertes.fr/docs/00/21/59/67/PDF/ Rapport_interne_1.pdf>

[20] Holmqvist, K., Nyström, M., Andersson, R., Dewhurst, R., Halszka, J. & Van De Weijer, J. (2011). Eye tracking: A comprehensive guide to methods and measures. Oxford University Press, 560 pp.

[21] Glenstrup, A. J. (1995). Eye controlled media: Present and future state. Copenhagen, 90 pp. PhD Thesis. University of Copenhagen, Laboratory of Psychology.

[22] Dual Purkinje Eyetrackers. Faculteit Psychologie en Pedagogische Wetenschappen - KU Leuven [online]. [cit. 2012-04-11]. Dostupné z:
http://ppw.kuleuven.be/english/lep/resources/purkinje

[23] Biedert, R., Buscher, G., Dengel, A. (2009). The EyeBook - Using Eye Tracking to Enhance the Reading Experience. In: Informatik-Spektrum, Vol. 33, Nr. 3, 2010, pp. 272 - 281.

[24] Iwasaki, M., Inorama, H. (1986). Relation Between Superficial Capillaries and Foveal Structures in the Human Retina (with nomenclature of fovea terms). In Investigative Ophthalmology & Visual Science, vol. 27, pp. 1698-1705, 1986, IOVS.org

[25] Pernice, K., Nielsen, J. (2009). Eye Tracking Web Usability: How to Conduct and Evaluate Usability Studies Using Eyetracking. Nielsen Norman Group, USA, 163 pp.

[26] Komogortsev, O. And Khan J. (2009). Predictive compression for real time multimedia communication using eye movement analysis. ACM Transactions on Multimedia Computing, Communications and Applications 6

[27] Salvucci, D. D., Goldberg, J. H. (2000). Identifying fixations and saccades in eye tracking protocols. In Proceedings of the Eye Tracking Research and Applications Symposium, New York: ACM Press, pp. 71-78.

[28] Just M. A.,Carpenter, P. A. (1976). Eye fixations and cognitive processes. Cognitive Psychology 8: 441–80

[29] Steinke, T. R. (1987). Eye movement studies in cartography and related fields. In Cartographica: The International Journal for Geographic Information and Geovisualization, Vol. 24, No. 2, pp. 40 - 73.

[30] Jones, R. E. et al. (1950). Eye movements of aircraft pilots during instrument landing approaches. In Aeronautical Engineering Review, Vol. 9, No. 2. (1950), pp. 24-29.

[31] Coltekin, A. et al. (2009). Evaluating the Effectiveness of Interactive Map Interface Designs: A Case Study Integrating Usability Metrics with Eye-movement Analysis. In Cartography and Geographic Information Science, Vol. 36, No. 1, pp. 5-17.

[32] Coltekin, A. et al. (2010). Exploring the efficiency of users' visual analytics strategies based on sequence analysis of eye movement recordings. In International Journal of Geographical Information Science, Vol. 24, No. 10, October 2010, pp. 1559–1575.

[33] Opach, T., Nossum, A. S. (2011). Evaluating the usability of cartographic animations with eye-movement analysis. In Proceedings of the 25th International Cartography ConferenceICC, Paris, 11 pp., ISBN 978-1-907075-05-6

[34] Fuhrmann, S., Komogortsev, O., Tamir, D. (2009). Investigating Hologram-Based Route Planning, Transactions in GIS, 2009, pp. 177–196

[35] Popelka, S., Brychtová, A. (2011): Metody virtuální rekonstrukce zaniklé pevnosti Olomouc. Historická geografie 37/2 Historický ústav AVČR, Praha, pp. 213-230.

[36] ICA Commision on Use and User Issues in Cartography and Geo-information Processing and Dissemination (2012). http://www.univie.ac.at/icacomuse/index.php?title=Main_Page

[37] ICA Commission on Cognitive Visualization (2012). https://www.geo.uzh.ch/microsite/icacogvis/ mission.html

[38] Raiha, K. J. et al. (2005). Static Visualization of Temporal Eye-Tracking Data. In Human -computer Interaction - INTERACT 2005, Lecture Notes in Computer Science, Vol. 3585/2005, pp. 946-949.

[39] Jarodzka, H., Holmqvist, K., & Nyström, M. (2010). A vector-based, multidimensional scanpath similarity measure. In C. Morimoto & H. Instance (Eds.), Proceedings of the 2010 Symposium on Eye Tracking Research & Applications ETRA ’10 (pp. 211-218). New York, NY: ACM.

[40] Privitera, C. M., Stark, L. W. (2000). Algorithms for Defining Visual Regions-of-Interest: Comparison with Eye Fixations. IEEE Transactions on Pattern Analysis and Machine Intelligence (PAMI) 22, 9, 970–982.

[41] Duchowski, A. T., Driver, J., Jolaoso, S. Tan, W., Ramey, B. N., Robbins, A. (2010) Scanpath comparison revisited. In Proceedings of the 2010 Symposium on Eye-Tracking Research Applications (ETRA '10). ACM, New York, NY, USA, 219-226.

[42] Voßkühler, A., NORDMEIER, V., KUCHINKE, L., JACOBS, A.M. (2008). OGAMA - OpenGazeAndMouseAnalyzer: Open source software designed to analyze eye and mouse movements in slideshow study designs. Behavior Research Methods, 40(4), 1150-1162.

[43] Voženílek, V., Dobešová, Z. (2005). Metadescription - first step in an atlas production. In Co zwie sie koncepcja mapy?, Wroclaw, 154 pp.

[44] Fisher, R. A. (1925). Statistical Methods for Research Workers. Macmillan Pub Co. 362 pp.

[45] Hägerstrand, T. (1970). What about people in Regional Science? In Papers of the Regional Science Association, Vol. 24, pp. 6–21.

[46] Kraak, M.-J., Koussoulakou, A., 2004, A Visualization Environment for the Space-Time-Cube. Developments in Spatial Data Handling In Developments in Spatial Data Handling, pp. 189-200.

[47] Andrienko, N., Andrienko, G. And Gatalsky, P., (2003). Visual data exploration using Space-Time-Cube, In ICC 2003 Proceedings, Durban, south Africa, pp. 1981 – 1983.

[48] Nossum, A. S., Opach, T. (2011). Innovative analysis methods for eye-tracking data from dynamic, interactive and multi-component maps and interfaces, In Proceedings of the 25th International Cartography ConferenceICC, Paris, ISBN 978-1-907075-05-6

[49] Montello, D. R. (2002). Cognitive map-design research in the twentieth century: theoretical and empirical approaches. In Cartography and Geographic Information Science, 29, pp. 283-304.

[50] Slocum, T. A., Blok, C., Jiang, B., Koussoulakou, A., Montello, D. R., Fuhrman, S., Hedley, N. R. (2001). Cognitive and usability issues in geovisualisation. In Cartography and Geographic Information Science, 28, pp. 61-75.

[51] Downs, R. M., Stea, D. (1977). Maps in Minds. Reflection on cognitive mapping, New York, Harper & Row.

[52] Pravda, J. (2006). Metódy mapového vyjadrovania – klasifikácia a ukážky. Slovenská akadémia vied, Geografický ústav Bratislava, 128 pp.

IntechOpen