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Exploring Effectiveness of Uncertainty Visualization Methods by Eye-Tracking

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Abstract

Several visualization techniques for the portrayal of uncertainty have been developed, but there is a gap in transferring knowledge between researchers and final users due to the lack of knowledge about the effectiveness of these visualizations. In this paper, we present a user study that evaluates the perception of uncertainty of the most commonly used techniques for visualizing uncertainty. The study uses data that was designed to represent the uncertainty on maps and images. An eye-tracking study was conducted to assess the differences in user behaviour during scanning the uncertainty visualizations. The search tasks involved primarily finding areas with the least or the most uncertainty. The second part of the research dealt with the usage of uncertainty legends. Eye-tracking can help to understand questions concerning the user's strategy of the information searching. The eye-tracking method can be considered as the objective one, because it is not influenced by the opinion of the monitored person. To assess graphic effectiveness, eye-tracking methods can help to provide a deeper understanding of scanning strategies that underlie more traditional, high-level accuracy and task completion time results. Eye-tracking methods entail many challenges, such as defining fixations, assigning fixations to areas of interest, choosing appropriate metrics, addressing potential errors in gaze location, and handling scanning interruptions. Special considerations are also required before the designing, preparing, and conducting of eye-tracking studies. Discovered principles can be used in incoming theoretical evaluations of existing or newly developed uncertainty visualization techniques. In addition, the framework developed in this user study presents a structured approach to evaluate uncertainty visualization techniques, as well as provides a basis for future research in uncertainty visualization.

Keywords: eye-tracking, uncertainty, gaze, visualisation

1. Introduction

For the understanding, modelling and subsequent visualization of complex processes, sufficient information, data and especially perfect comprehension of all the natural processes and components are essential but often missing (Otýpková *et al.*, 2011). Subsequent modelling and visualization of these processes are, therefore, not possible without a certain degree of approximation. If it is just the visualization which has been selected to communicate the resulting data and related work, the output should also include a reference to the respective associated uncertainty. This means that the map end user must be familiar with the nature of the data and the degree of data uncertainty. If the user is not aware of this very fundamental aspect, it is possible for the data to subsequently be misunderstood and misinterpreted (Olston and Mackinlay, 2002).

There exist several research studies on user perception and evaluation of the applicability and effectiveness of visualisation.. Eye-tracking is one of the evaluations rarely used. Based on the results of eye movement analyses, many questions that have not yet been adequately discussed in the area of uncertainty visualisation, can be answered. For example how users obtain information from the map or particular visualisation, what is the strategy of reading, how often users look to the specific area or how easily can map symbols be interpreted.

2. Visualization of Uncertainty

The presentation of uncertainty still remains an unsolved problem, both in the field of cartography and the visualization of any information in various sectors of human activity. A wide variety of visualization algorithms is are used to visualize uncertainty. Research activities within the area of uncertainty visualization can primarily be primarily divided into two approaches in terms of comparative and combined maps. In the first case, uncertainty in maps is depicted separately from the primary data so that a separate map is created for the selected attribute and the uncertainty expression. In the case of combined maps, the selected attribute and its uncertainty are visualized in one map using appropriate graphic variables. Basically, we can talk about bi-variate maps (Ware, 2009) which use a combination of two variables.

3. Usability Studies

The term usability is defined by ISO 9241 (1997) as “the effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments”. Satisfaction quantizes subjective user impressions while dealing with such indicators as operability and learn-ability of a given task. The usability can reveal qualities of the product as well as the lack of its functionality, which usually arises during the design phase of a product (Hub *et al.*, 2011)

There exists a number of usability studies, which vary in degree of objectivity. These methods of usability evaluation include focus group studies, interviews, direct observations, think-aloud protocols, retrospective think-aloud protocols, and screen captures (Li *et al.*, 2011). The results of all these methods can be affected by the respondent’s inaccuracies of answering that may arise when users fail to fully realize and describe all the factors, which have affected them during the experiment or answer as they think they should respond.

If the experiment is properly designed, eye movement recordings do not rely on self-reporting, therefore it can be considered an objective method and can enhance traditional performance tests, protocol analysis, and walk-through evaluations of a system (Goldberg and Kotval, 1999). Usage of the eye tracking tools adds a different aspect to the usability field for the reason that it provides objective and quantitative evidence to investigate the user's cognitive processes such as visualization and attention (Duchowski, 2002).

4. Eye-tracking

Eye-tracking is a technique whereby an individual's eye movements are measured so that the researchers know both where a monitored person is looking at any given time and the sequence in which their eyes are shifting from one location to another (Poole and Linden, 2005).

Vision is the strongest of the senses in humans (Coltekin *et al.*, 2010). Therefore, it is natural to use graphics to enhance cognition and understanding of geographical information. Effective graphics are essential for understanding complex information and completing tasks. To assess graphic effectiveness, eye tracking methods can help provide a deeper understanding of scanning strategies that underlie more traditional, high-level accuracy and task completion time results (Goldberg and Helfmann, 2010). Modern eye-trackers (devices capable to monitoring eye movements) are based on a remote pupil-and-corneal-reflection method (Holmquist *et al.*, 2011). They rely on the measurement of visible features of the eye, e. g. pupil, iris-sclera boundary and corneal reflection of a closely situated direct infrared light source. The reflected light is recorded by a video camera or a specially designed optical sensor. The information is then analysed to extract eye rotation from changes in corneal reflections.

Data sampling frequency depends on parameters of the particular eye-tracking system. It can vary from the slowest systems with 20 Hz to more than 1000 Hz.

Data recorded by eye-trackers typically contains each subject's gaze coordinates within an observed stimuli, pupil diameter, user interactions (e.g. mouse or keyboard clicks) and other related metrics sampled and time-stamped according to a sampling frequency of the eye-tracker. In order to get meaningful results it is necessary to classify the original data. The main role of any eye movement classification algorithm is to break the eye position temporal stream into basic eye movement types, as well as provide a set of characteristics about each movement type detected. The most researched eye movements that are employed in human computer interaction are fixation and saccades. Fixation is a kind of movement when the eyes remain still over a period of a time. The rapid motion of the eye from one fixation to another is called a saccade (Holmquist *et al.*, 2011).

5. Usability studies and uncertainty visualisations

Although the need to visualize the uncertainty has been identified (Harrower, 2003), a consensus over the best way to communicate it is still missing. Some experts argue that the addition of another variable in the form of uncertainty leads to problems in communication and therefore, to wrong conclusions and decisions. Nevertheless, Evans (1997) confirmed in his study that all tested participants were able to understand and interpret the uncertainty visualized. Pappenberger and Beven (2006) also reject the argument that people making decisions are not able to understand the division and visualization. They express the opinion that this is a problem of communication rather than an issue of misunderstanding.

Research on usability studies in uncertainty visualisations have been performed from 1990. Many tests on several techniques were conducted. Evans (1997) assessed Static Colour Bivariate Maps (MacEachren *et al.*, 2005). Fisher examined the Flickering Animation method (1993) and MacEachren considered Toggling (1992). Later MacEachren *et al.* assessed Adjacent Maps (1998) and a Colour Model (2005) The Texture Overlay method was assessed by Kardos *et al.* (2003). The Toggling method was the least preferred by all users. Sanyal *et al.* (2009) found that the perception of uncertainty is not uniform. The study results of Kobus *et al.* (2001) as well as Hope and Hunter (2007) suggest that the knowledge of users has a major impact on their decisions.

6. Methodology

The aim of our study was to evaluate the effect of uncertainty visualisations on eye movements and performance in map-related tasks. The study involved decision making questions where the participants were presented with the visualisation (contour maps, symbol maps, adjacent maps). They had to carefully analyse the data and uncertainty together in order to answer questions that involved finding areas with the least or most uncertainty. As an additive factor the study also compared user performance with and without the use of the legend.. Tests were assembled to test the user's perception of uncertainty visualisations using the eye tracking device. For experimental design, the manufacturer software SMI Experiment Centre was used and experiments were performed using the SMI RED 250 eye-tracker with a 120 Hz sample rate. The data collected during analyses were executed in BeGaze, OGAMA (Vosskühler et. al., 2008) and R software. We chose people which had similar experiences with maps and based on their educational level were considered as experienced in dealing with uncertainty in their data. Each experiment was designed as a set of stimuli containing maps with uncertainty visualisation. Half of the participants used visualizations with a legend, and half used the same visualisation without a legend. The purpose of this experiment was to evaluate the user's behaviour during answering the spatial query and the influence of a legend during testing. Stimuli included several visualization methods. Some stimuli were adjacent visualisations represented as a pair of maps.. After acquiring an idea about the different uncertainty visualisation methods and the decision making problems, users had to mark the area in the map.

Through the correspondence between the performances (statistics of eye tracking data) and the preferences, the learn-ability aspect of uncertainty visualisation methods was assessed. This was done because there is a discrepancy among experts regarding the influence of learning and acquired knowledge during testing. Based on testing, we can deduce that the perception of areas with a low level of uncertainty differs from the perception of places with a high degree of uncertainty.

For a comparison between users we used Areas of Interest (AOI). 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 the entry to the exit. The dwell has its own duration, starting point, ending point, and dispersion.

7. Preliminary results

A legend expressing the uncertainty of data is a very important component of the map. This element in maps in most cases attracts significant attention. The results for the versions with and without the legend are very different. The difference of correct answers within the same map with and without a legend was 45% in extreme cases. An average difference was around 20%. Results also showed that the length of observation did not affect the accuracy of answers in general and particular users have different reading strategies which were proven by AOI vs. time charts.

8. Conclusion

The visualisation of uncertain information affects eye movements in all of the measured metrics. The difference in fixation duration in the several visualisations may indicate that it was regarded less complex than the other or that the contrast and spatial frequencies differed between the visualisations. However, due to the research design the individual variation in eye movements may have affected the results. The results showed that the experimental task affects eye movement. In order to derive a stronger evaluation, it will be necessary to choose inexperienced participants and participants from different domains. Due to easier access to eye-trackers, we can expect, more numerous and deeper research on different aspects of uncertainty visualisation readings. Finally, the eye tracking technology will definitely bring promising results in the future that will help the creators of various visualizations to reduce the misunderstanding and misinterpretation due to uncertainty visualizations.

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