Evaluating the usability of cartographic animations with eye-movement analysis

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1. Eye-tracking as an evaluation method

Availability of time-series spatial data and wide access to computer tools has resulted in broad use of cartographic animations. A growing amount of animated maps poses new challenges, in which the efficiency of cartographic communication is of concern (Opach 2005).

There are various methods for studying usability of maps in general. The methods range from traditional surveys (Suchan and Brewer 2000) to unobtrusive data gathering such as eye-tracking. In recent years the use of eye-tracking in cartography has increased (Fabrikant *et al.* 2008, Çöltekin *et al.* 2009, Brodersen *et al.* 2001, Fabrikant *et al.* 2010, Li *et al.* 2010). Availability as well as development of both eye-tracking software and hardware is believed to be the major reason for this.

Eye-tracking provides the ability to record eye movements in unobtrusive manner relying on specialized equipment. Earlier studies using eye-tracking have primarily treated the stimuli as static representations. Although, several studies have also focused on exploring new approaches or analysis methods for eye-tracking data to accommodate better cartographic stimuli and qualities associated with this (Garlandini and Fabrikant 2009, Çöltekin *et al.* 2010).

Despite the increased focus on eye-tracking, the question remains unanswered on how eye-tracking is suitable as an evaluation method with cartographic animations as stimulus. In this paper we explore the suitability of eye-tracking on two different cartographic animations in an attempt to answer this question.

We have conducted two eye-tracking experiments with 10 participants each for both an isolated cartographic animation (semistatic animations) and a complex animated map (the Kampinos Forest animation). We have used standard analysis tools to assess and gain experience on their strengths and weaknesses when cartographic animations are used as stimuli. The experience gathered in this process is described throughout this article as well as our suggestions for improvements.

2. Introduction to the animations

2.1 Semistatic animations, integrating past, present and future

Traditional map animations have several issues associated with them. The most notable are split attention and disappearance (Harrower 2003, 2007). They are both affected by the fact that animations display frames with changing content. In effect, the viewer needs to pay attention to the animation in order to not miss information. In addition, the animation may have several different elements that are attracting the user's attention, such as timeline or legend. This causes the viewer to choose between the information and risk the possibility of losing information displayed at the same moment on other parts of the animated map.

Static maps are not affected by the same issues as map animations. First of all the information does not change, allowing the viewer to use unlimited amount of time for viewing. However, static maps are ill-suited, compared to animated maps, in displaying information which changes over time. Animations have been the most accepted by the non-expert user.

Semistatic animation is a concept which combines the qualities from both static and animated map representations (Nossum 2010). The idea is to represent all information of an animation in every single frame of the animation. This allows the user to visually look back and forth in time in the animation without the need to control the flow of the animation. Figure 1 illustrates two different proof-of-concept implementations of the semistatic concept using weather and temperature maps as a case study. Figure 2 explains the symbols used to incorporate the complete information in the map animations. Temperature and weather were chosen to investigate the possibility of different information classes: numeric (temperature) and textual (weather/symbolic).

A web experiment has been conducted to test the performance of the concept (Nossum 2010). In total the experiment included over 200 participants and aimed at comparing the semistatic implementation with its traditional equivalent. The analysis has given surprising results related to the performance of different tasks in comparison with our expectations. In later sections we will compare the results from the web experiment with the outcomes from the eye-tracking tests carried out in this study.

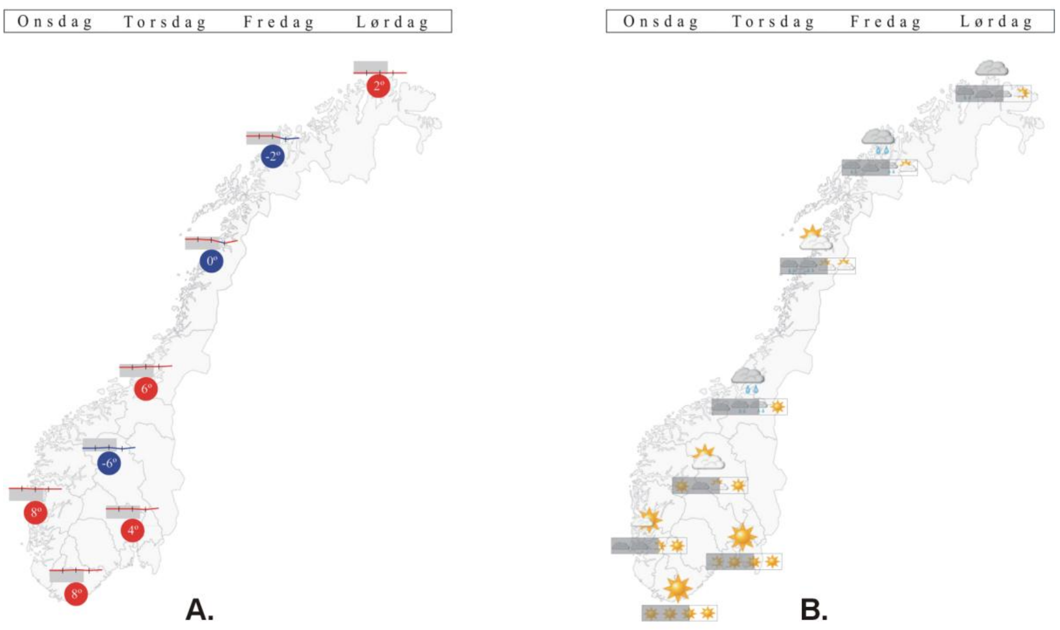


Figure 1. Proof of concept implementation of the semistatic concept: A. temperature map animation, B. weather map animation.
Animations available at: http://geomatikk.ntnu.no/projects/semistatic/.

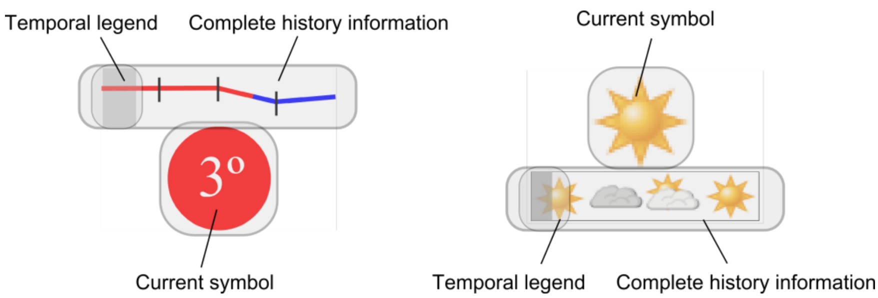


Figure 2. Essential elements of the symbols incorporating the complete information of the animation. To the left: Temperature symbol with numeric information visualized as a line graph. To the right: Textual information visualized using pictograms.

2.2 The Kampinos Forest animated map, multi-scenario and multi-component

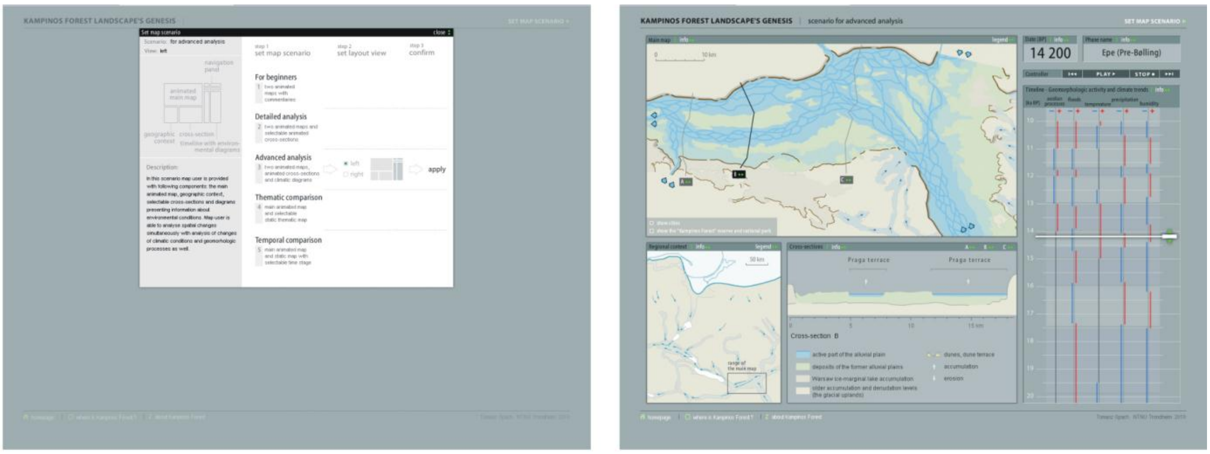
Multi-scenario and multi-component animated map of the Kampinos Forest (Figure 3) was introduced to facilitate understanding the spatio-temporal landscape changeability as well as to investigate factors which influence an effective use of complex cartographic applications.

When visualizing spatio-temporal geographic changeability it is often not enough to display one animation (Monmonier, 1992). Sometimes it needs to be coupled with other “components” (maps or non-cartographic presentations) to identify the associations between different variables. Variety of used components depends on topics and presented areas. In general, the following components can be listed: the main animated map, various navigation panels, animated/static cross-sections, animated/static diagrams and small animated maps with geographic context.

The usefulness of multi-component animated maps relies on their functional advantages. Of great importance is to investigate possible fields of use and to define suitable sets of components. Therefore the cartographer should specify the sets of components which are important for the knowledge acquisition and the task solving. We called these sets of components “map scenarios”. The Kampinos Forest animated map has been divided into five map scenarios. Figure 4 shows their structure.

It is also the cartographer who should make easy accessible map scenarios. To meet this challenge we designed the opening window (Figure 3A) – an introductory element of the map interface which describes all map scenarios and map components in a suggestive manner.

The linking of various visualization techniques may increase the efficiency of the cartographic communication process. However, the role of multi-component animations should be investigated deeper. Split attention is of concern as the main disadvantage when using such cartographic applications. As a result the eye-tracking technique has been employed for revealing how the Kampinos Forest animated map is used.



A. B.

Figure 3. Screen snapshots captured for the opening window (A) and the scenario “for advanced analysis” (B). This scenario comprises the main animated map, the small animated map, animated cross-sections and navigation components with set of graphs.
Prototype available at: http://www.geomatikk.ntnu.no/prosjekt/KampinosForest/.

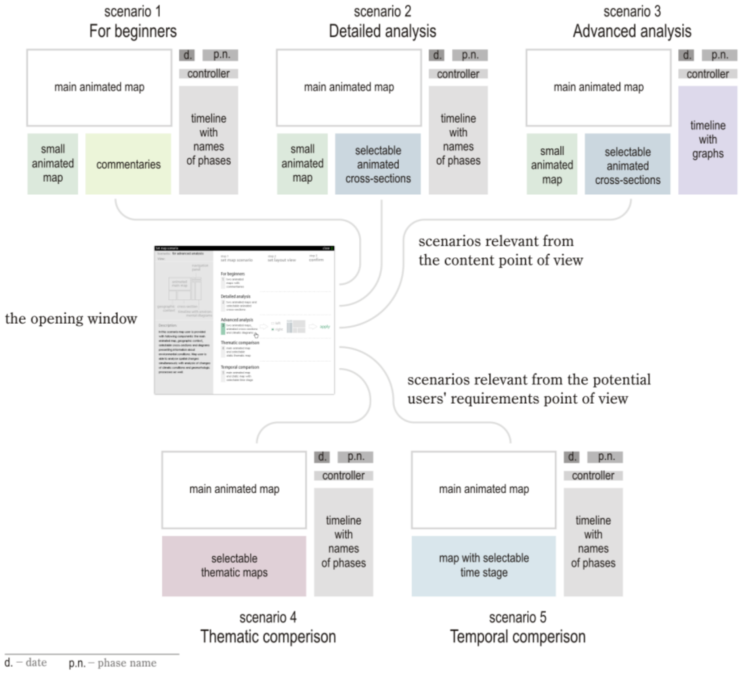


Figure 4. Five map scenarios implemented in the Kampinos Forest animated map.

3. Experiment

The experiment was conducted during week 12 in 2010 in the usability laboratory of the Norwegian University of Science and Technology and St. Olavs Hospital. In total 10 participants were recruited. All tests were performed in a dedicated room. The hardware used was a Tobii X120 eye-tracker and PC with a 19" screen. Video and audio recordings were controlled by Tobii Studio using a standard HD web camera.

The experiment was divided into two consecutive parts and lasted around 35 minutes per participant. The first part consisted of the semistatic map animations; the second part comprised the Kampinos Forest map. The stimulus were implemented as web pages and displayed using the built-in browser functionality in Tobii Studio. During the tests the participants were presented tasks that they should solve by either using or looking at the displayed stimuli. Answers on the tasks were recorded using HTML forms with pre-defined options.

4. Analysis of eye-tracking data

4.1 Semistatic animations analysis/results

The results from the earlier web experiment (Nossum 2010) are used in comparison against the eye-tracking experiment. Several differences in the performance of semistatic and traditional animations were identified in the mentioned web survey. The eye-tracking experiment used the exact same stimulus and questionnaires as the web experiment did. But, of course with fewer participants the results are not representative for a population. However, the results follow the same pattern as the web experiment.

We use both of these results as basis for the following analysis. The eye-tracking data provides an insight into the behaviour and can support better the exploration of *why* the performance differs between the web experiment and the eye-tracking experiment.

The eye-tracking experiment was divided into two map animations: temperature and symbolic weather. The participants were given three tasks for each animation: trend on one location, trend over space and time and a memory task.

We have used the built-in areas of interest (AOI) tool in Tobii Studio to calculate statistics of the eye-movement data. Figure 5A shows an example of this. Tobii Studio includes additional tools, where "heat maps" and "gaze plots" are the most common. For this experiment the gaze plot and heat maps were not suitable. Figures 5B and 5C show examples of a gaze plot and a heat map for one task only. The gaze plot results in an enormous visual clutter, not suitable to use further. The heat map aggregates too much and not respecting the temporal variation which results in not uncovering anything other than what we already knew; that participants were going to look at the points of interest. This is reminiscent of the early arguments against using eye-tracking for cartographic studies (Fabrikant *et al.* 2008).

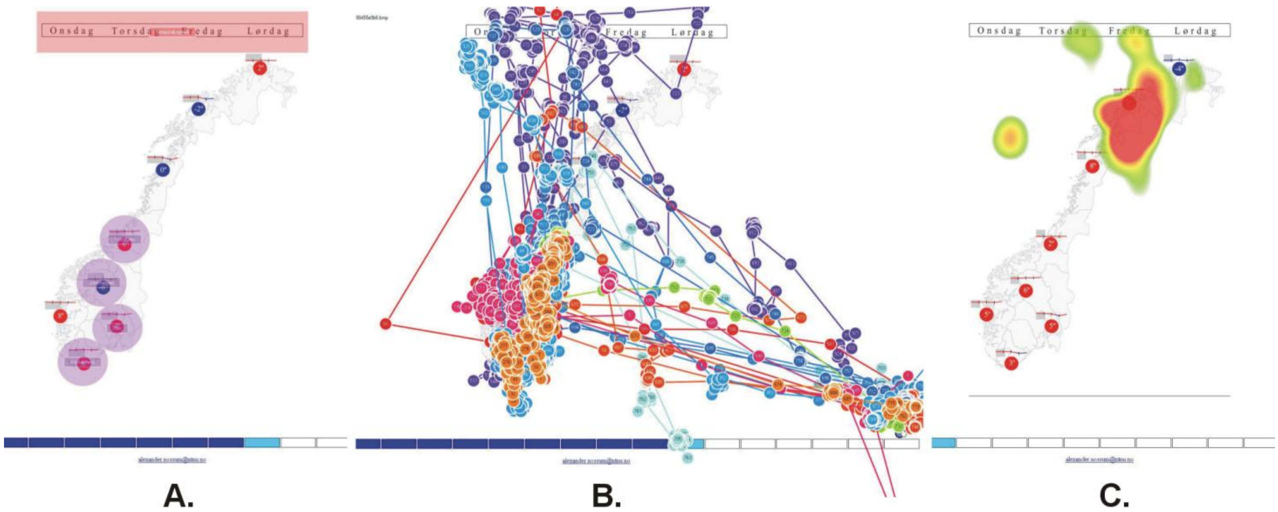


Figure 5. Examples of: (A) areas of interest, (B) gaze plot and (C) heat map.

The statistics produced by Tobii Studio using the defined AOIs provided more insight into the participant's behaviour. For each task, for both the temperature and symbolic weather animation, we have analyzed three different statistics: fixation counts, observation length and time to first fixation. For all of these statistics the variance in the data is unfortunately very high. This can be due to few participants and that the tasks and visual stimulus open for a lot of variance in viewing strategies and general user behaviour.

As a result of the very high data variance the statistics can only be used to provide indications on a general pattern and not provide representative results. However, several interesting patterns were discovered in the analysis of the data.

The results from the earlier web experiment (Nossum 2010) indicated that there was a significant difference in the performance (correct answers) between the semistatic and the traditional animation. Based on this we expected the viewing behaviour to be similarly different between these two types. However, in general the analysis of the eye-tracking data revealed that the viewing behaviour were surprisingly similar. All three of the metrics used indicated very similar viewing strategies and behaviour. Figure 6 shows the results of the questionnaires from the web experiment and the eye-tracking experiment respectively. Both of these results indicate a difference in the performance of the two different animations. Based on this it is natural to assume that the cause comes from different user behaviour. However, Figure 7 shows the results from the eye movement analysis. All of the three metrics shows a very similar behaviour for both the traditional and the semistatic animations. There are only minor differences between the fixation counts and the observation length. The similar behaviour is in some ways contradicting our initial beliefs from the questionnaires. However, the eye movement analyses are based on 10 participants where the data has a very high variance. Averaging the data may produce a false view of the actual behaviour.

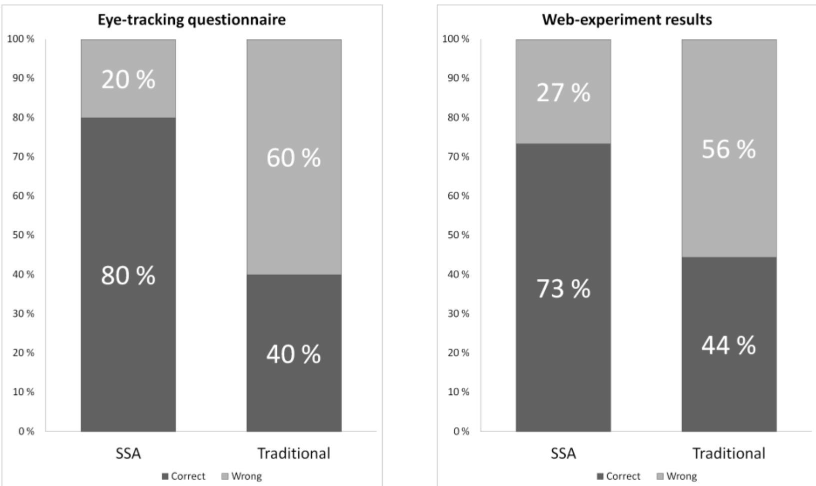


Figure 6. Results from the questionnaires in the web experiment and eye-tracking experiment respectively.

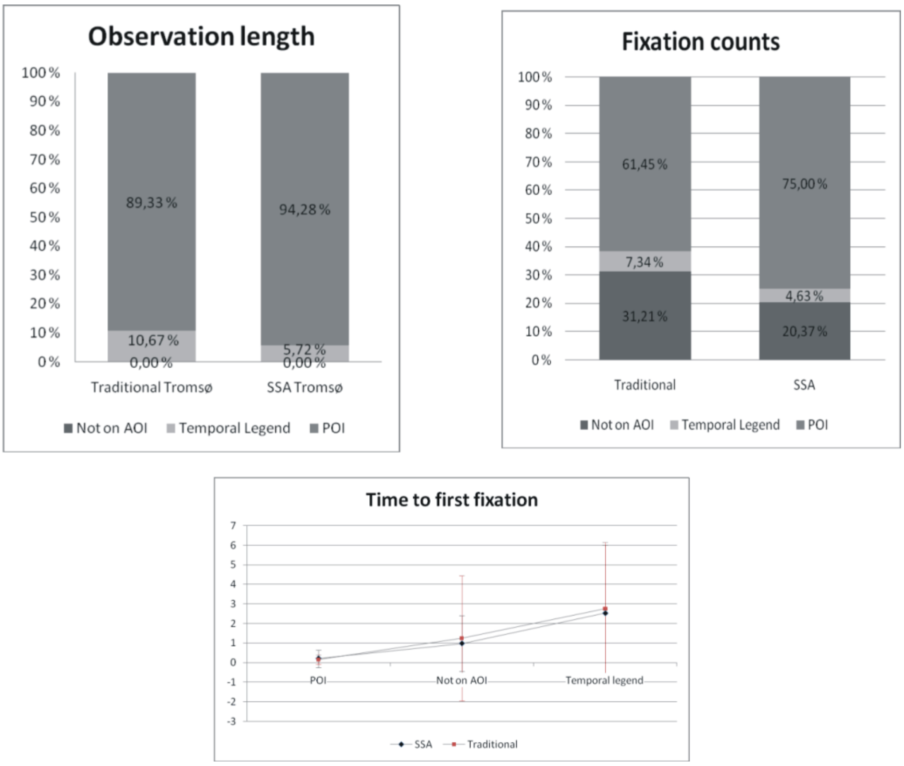
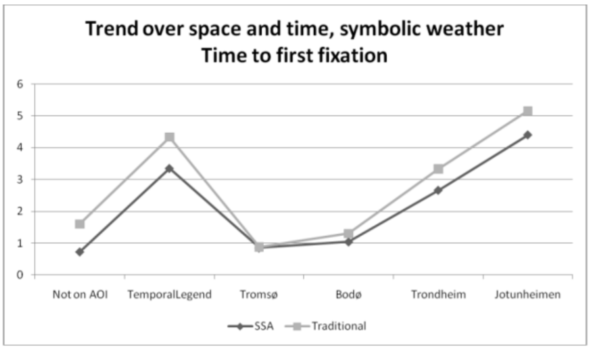


Figure 7. Results from the eye movement analysis. Showing very similar behavior for both the traditional and the semistatic animations.

The observation of different indications based on different experimental techniques underlines the necessity of including several methodologies in evaluating maps and map animations especially. The results presented here do not provide an in-depth answer to why the difference in answers occurred. Other more sophisticated analysis methods are needed to properly analyze the individual participant and compare their eye movements both in relation to the spatial behaviour but also in relation to the temporal dimension. As illustrated here the standard analysis methods do not facilitate this. Although Tobii Studio does include the possibility of investigating individual participants and re-play their eye-movements with the stimulus – we find this method not satisfying. Even with our experiment involving only 10 participants the data becomes too rich to manually re-play and analyze in an adequate and accurate way.

Despite the similarities in most of the eye movement analyses there are some interesting results we like to emphasize. The task; Trend over space and time was believed to be the most challenging task. The participants were asked to imagine they were planning a trip and were interested in the weather. They spent one day at each location. The semistatic animation has the advantage that it is possible to look both in the past and future of the information, regardless of the animations current time. This is not possible in the traditional version where the user needs to pay close attention to both the current time and to look at the correct position at the correct time in order to get the correct information.

Figure 8 shows the graph over time to first fixation for the different AOIs, one for the symbolic weather map and one for the temperature map. The results from both questionnaires indicated that for the symbolic weather map the semistatic animation performed worse than the traditional animation. For the temperature animation the results were opposite and the semistatic animation performed better than the traditional animation. Interestingly the graphs in Figure 8 shows that for both the symbolic weather animation as well as the temperature animation the viewing strategy seems to be more or less equal. The similar observation is made for both observation length and fixation counts. This can indicate that the additional information included in the semistatic, symbolic weather animation distracts or confuses the users and do not support this task very well. These findings would have been very hard and nearly impossible to discover from a web experiment alone.



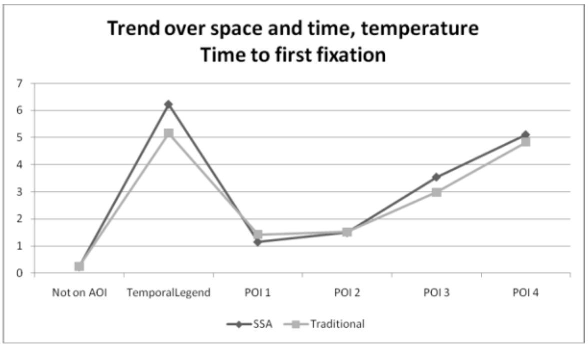


Figure 8. Time to first fixation on relevant areas of interest for both symbolic weather animation and temperature animation for the task; trend over space and time.

The eye-tracking experiment has provided us with insight and experience on its usage for evaluating cartographic animations. The results were, in general, quite surprising. Almost all of the metrics we used showed more or less similar behaviour for the traditional and the semistatic animation. The results from the questionnaires, both from the earlier web experiment and during the eye-tracking experiment indicated a large difference in performance – we expected as such a similarly large difference in the eye movements.

4.2 The Kampinos Forest animated map analysis/results

When conducting this part of the research two detailed questions (research problems) have been specified: 1) Is a complex map interface usable without a tutorial session? 2) Do map users follow various map components when using complex map animation? The first question refers to the idea of intuitiveness. We assumed that a complex map system does not have to be equipped with a tutorial session. However, to keep users performance with a high level of confidence, the concept of “opening window” has been introduced (Figure 3A). Split attention is of concern while carrying on investigations on animated maps (Harrower 2003, 2007). Therefore we focused on this challenge while shaping the second research problem.

For every map scenario of the Kampinos Forest map a separate task was proposed – in total five tasks. They consisted of two parts: At the beginning the participants were asked to select the most suitable map scenario. If the participant chose the wrong scenario, we asked to change for the correct one. After the map scenario displayed, the participants were asked to answer the question.

Three kinds of data have been recorded after finishing user testing: eye-movements, chosen scenarios and given answers. We had to omit one participant due to low accuracy.

Figure 9 shows participants’ answer times for the tasks. On average they needed 41,9s for choosing map scenario and four times more for answering question. People took much longer to choose a map scenario in initial tasks what might be caused both by the learning effect and the routine as well. We also observed major differences between response lengths for various tasks. The most time consuming was task 4, the least task 5. These metrics do not vary greatly across participants thus we argue that participants’ answer times depend on tasks’ levels of complexity.

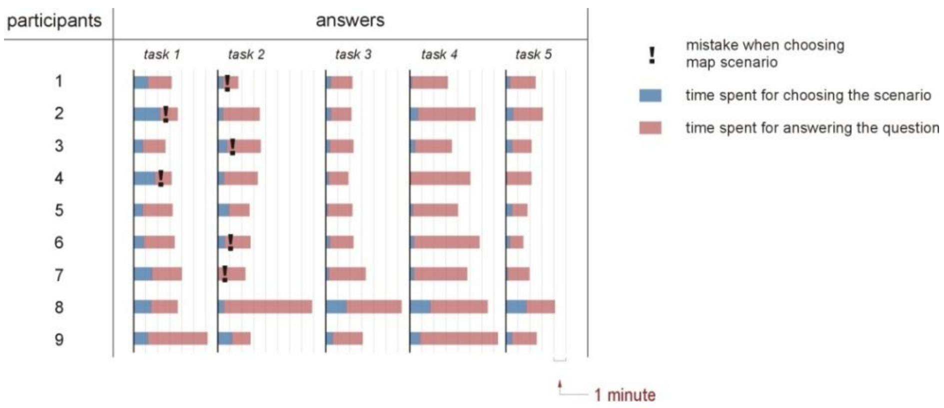


Figure 9. Participants’ answer times.

In general, the participants have managed with their attempts to choose the most suitable scenario and mistakes occurred only in two first tasks. Further the eye movement analysis gave us possibility to get better insight into participants’ behavior. We delineated AOIs and analyzed descriptive statistics. In task 1 participants who have chosen incorrect scenario surprisingly were viewing the opening window almost twice longer (M=119,7s vs. M=67,1s) and paid more attention on its manifold elements. For instance they were looking at the “Description panel” (Figure 10) three times longer and almost four times longer at the “Rest of selection panels”. These differences are suggestively presented on heat maps (Figure 10, variable: relative duration). Revealed facts may indicate that people who analyzed the opening window attentively failed to choose the correct map scenario. In contrary, those who were less attentive have succeed. However, this cannot be accepted as an exact explanation because participants could use more time due to incomprehension.

Eye-movement analysis of the data from task 2 revealed that participants who have chosen a correct scenario have been concentrating more on the "Correct selection panel" (Figure 11). On the other hand participants with an incorrect selection have been concentrating mainly on the first scenario selection area. Moreover they have been viewing the "Components description panel" more than four times shorter. It is likely that their wrong decision was caused by the routine.

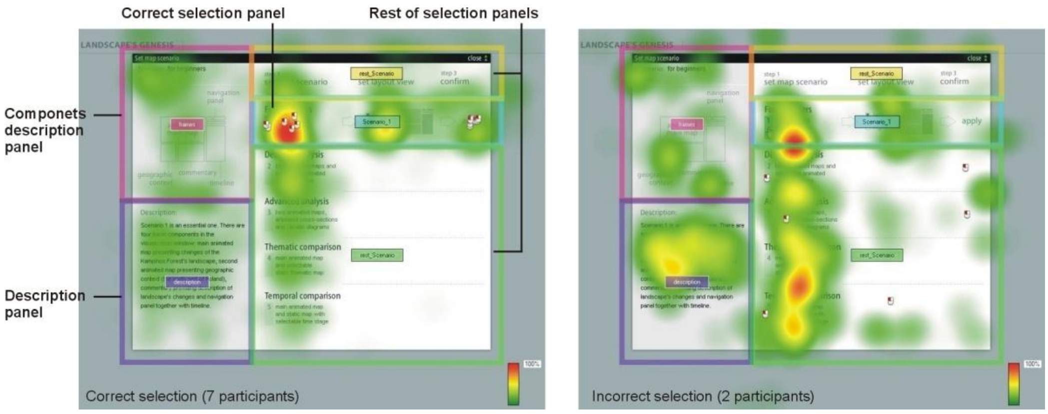


Figure 10. Two heat maps with delineated AOIs prepared for participants who made a correct choice (left) and a wrong choice (right) when selecting map scenario in task 1.

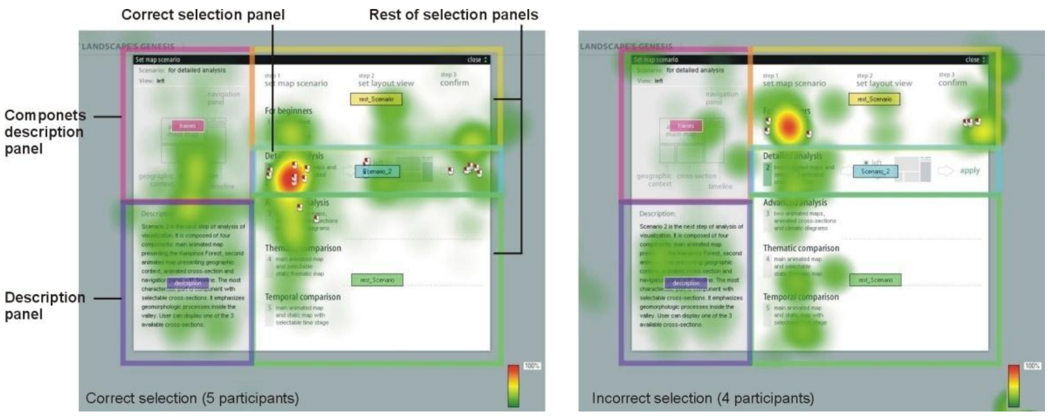


Figure 11. Two heat maps with delineated AOIs prepared for participants who made a correct choice (left) and a wrong choice (right) when selecting map scenario in task 2.

When responding most of participants selected correct answers (Figure 12). However, there were answers that surprised us. Only one participant succeeded to respond correctly in task 1. Analysis of the eye-movements revealed that this participant has been concentrating just on the interface area where the answer was "hidden". But similar behavior was also observed in few other participants who gave a wrong answer. Tasks from 2 to 5 the participants managed almost in total. Both task 2 and task 5 got one mistake. Two mistakes occurred in task 4. Their eye-movement analysis revealed that participants did not answer because they had not managed with displaying the legend component.

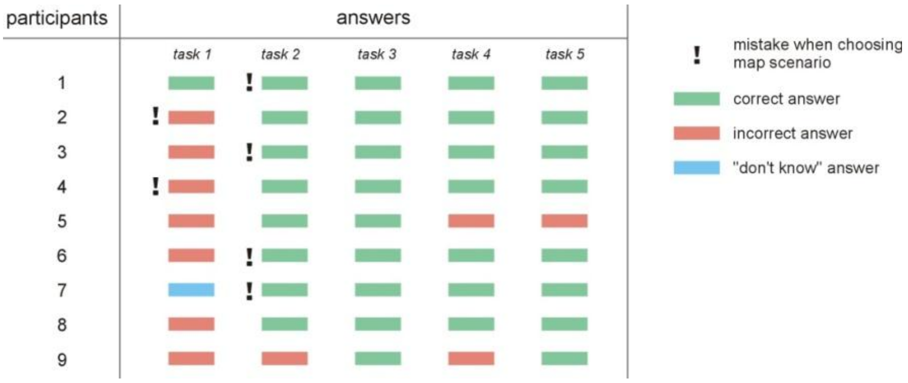


Figure 12. Participants' chosen scenarios and given answers.

The research question about simultaneous viewing of various map components is more confusing. Broadly speaking, on the basis of the experience of this research we argue that when using the eye-tracking as a research technique, stimulus should be designed especially towards this technique. The manner how participants were viewing the Kampinos Forest animated map depends on the research tasks not on the general behavioral patterns. That is why people have been mostly looking at these components where the answers were expected to be found. Moreover, it is obvious that the participants spent more time looking at descriptive component (e.g. 52% of total fixation length in task 1) than at illustrative part of the interface. It is nothing new that reading needs more time compared against viewing.

Additional information (e.g. about viewing sequences) could be obtained from the gaze plots analysis. The point is that when investigating a lot of or long trajectories visual overlapping makes it impossible to reveal patterns across participants. The gaze plots analysis is then useless.

The positive results of the tasks dealing with the Kampinos Forest map revealed that participants did not have problems neither with understanding the map's content nor with intuitive use of the interface. Their positive attitude towards the interface was visible in the self-confidence when using the opening window as well as other interactive elements. Although further eye-movement data analysis using AOIs and heat maps uncovered some interesting patterns it has not brought out a clarification. While the differences in behavior of participants who gave correct and incorrect answers were specified, exact explanation was not given. We might indicate *when* and *where* the difference occurred, but we cannot explain *why*.

Participants' ability to split attention appeared as doubtful and at least questionable. The AOI analysis uncovered that participants have been looking at several components during test sessions. However, due to the lack of suitable tools, the sequence analysis could not be provided.

5. Discussion and conclusion

General evaluation of two cartographic animations and gaining experience on use of eye-tracking for animated stimuli were of major importance for the study. We underline that only the standard tools were examined for the data analysis purpose.

First off all, only ten participants attended the test sessions. Thus when analyzing the data it is evident that the variances of the eye-movement metrics are high. This may be affecting the indications of the similar behaviour and in general our results as a whole. A useful experience is that the stimuli should be designed specifically for use in an eye-tracking survey. In order to avoid large data variance the stimuli could be designed to minimize the possibilities of different viewing strategies. However, this will inevitably also affect the point of performing an experiment – a proper balance is needed for the best outcomes.

The most important approach in both parts of the research were statistical metrics based on AOIs. These statistics are informative but also debatable. The eye-tracker used in this experiment proved to have accuracy issues, probably due to a simple calibration process. This becomes an issue when using AOIs that are defined in a crisp matter. Figure 13 illustrates this problem; several of the fixations are recorded as inside the blue AOI, however they are more likely to actually be within the purple AOI. Future work should take this into consideration. The concept of fuzzy sets could prove to be successful to address this problem. The AOIs would then not have sharp edges but allow the edges to be fuzzy with respect to a membership function. Fuzzy sets could also be applied in more general to the eye movements. Currently only discreet fixations are available. This eliminates the analysis of the peripheral vision (Irwin 2004, Fabrikant and Garlandini 2010). Introducing dynamic or fuzzy buffers around the fixations could allow for better analysis of the actual vision of the user and not only the discreet fixations.

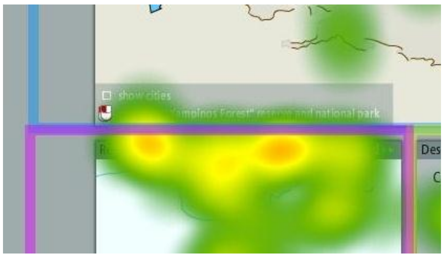


Figure 13. Which of the AOIs should the fixations be associated with? It is likely that due to an imprecise calibration the fixations are a bit shifted downwards comparing with the real viewing points.

Our study reveals that the eye-tracking approach could be applicable for examining the use of cartographic and interactive animations. However, some points need to be considered more thoroughly. We argue the following ideas should be examined in further works:

- Ability to investigate eye movements on individual level and being able to compare them immediately and in relation to the temporal dimension. Temporal alignment of the eye movement data can be an issue (Fabrikant *et al.* 2008). Stimulus design could limit this.
- Implement and standardize better aggregation techniques including both the spatial but also the temporal dimension of the eye movements. Current work on applying the space-time-cube is promising (Li *et al.* 2010).
- Consider applying fuzzy set theory on both the concept of fixations as well as areas of interest.
- Accuracy of the table mounted eye-tracker is an issue. Need better calibration methods. Other eye-trackers, such as head mounted and "glasses" may provide better accuracy.
- The complexity of the stimulus should be limited to facilitate better the analysis of the eye movements and get more high quality recordings with limited variance suitable for generalization.
- Combine the eye-tracking technique with other evaluation methods in order to get a more diverse picture of the user's behaviour. Especially when animated maps are used as stimulus**.**

Our conclusion is that eye-tracking as a method for evaluating cartographic animations is a valuable tool providing insight into the user's behaviour not easily accessible from other methods. However, there are still limitations associated with the accuracy of the recorder, but especially with the analysis methods.

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