DYNAMIC MAP LABELING FOR USERS

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Abstract

In this paper, the effectiveness of certain aspects of the label placement method on dynamic and interactive maps towards the user is examined. Reducing the number of labels which need to be considered by the method will drastically improve its efficiency. A user study is constructed to test whether these adaptations have an influence on the effectiveness of the map towards the user. The conducted tests utilize the eye tracking method to get an insight of the user's cognitive processes while performing a visual search on these maps. The obtained results reveal that the user does not notice the adaptations on the map. This leads to the conclusion that the efficiency of the map can be improved without causing distorting in the user's cognitive map.

Keywords: label placement, user study, eye tracking

1   Introduction

Dynamic and interactive maps are rapidly gaining popularity and likewise are their application fields and media on which they are presented. The first place is taken by the Internet, where already in 2003 more than 200 million maps were distributed each day. This is more than the number of maps printed on a daily basis (Peterson, 2003). The number of unique visitors of these maps has also rapidly grown over the years (van Elzakker, 2001; van Elzakker and Poppe, 2002; Mapquest, 2008). The interactive and dynamic maps can, on the other hand, also be found outside the reach of the Internet, for example in cars or on PDAs. Nowadays, these smaller maps form a group of dynamic, interactive maps which cannot be neglected anymore.

Especially for this last group it is of major importance that a user can retrieve as much information from the map as possible with just a single look at it. Crowding these low resolution maps with information will accomplish exactly the opposite. Well-considered

use of cartographic symbols is essential: colour (combinations), icons, labels, etc. These elements have to be designed and implemented from a user's point of view, because in the end, it will be this user who needs to be able to interpret the map while, for example, driving a car.

In this study, dynamic label placement for interactive maps is considered from a user's point of view. The objective is to get a detailed insight in the user's cognitive processes. This cognitive map gives information about how the provided data is stored and processed by the user. The focus lays on label transitions, by which the placement and movement of labels before, during and after a transition of the view is meant. These transitions are for example caused by user interactions, like panning. This is a critical moment because the user needs to be able to quickly orientate the map after the transition. Getting a better insight in the manner how a user stores and processes these label transitions, allows the creation of more effective maps. The visualization of these label transitions should be keyed to the cognitive processes, allowing faster processing of the data by the user.

2   Literature review

The complexity of the label placement problem is NP hard, even when only considering point objects (Marks and Shieber, 1991). Most of the research related to label placements on maps has been devoted to find efficient algorithms and heuristics which are applicable on static, printed maps or on dynamic (web) maps. The latter applications entail very strict constraints on the algorithms or heuristics, mainly related to their computational costs in terms of processing time and memory.

A number of authors proposed a computational expensive preprocessing phase to overcome the problems linked with interactive displays of maps. In this preprocessing phase, the data is structured in such a way – with the aid of graphs – that the objects are easily queried during the actual interactive phase. (Wagner et al., 2001; Petzold et al., 1999; Kakoulis and Tollis, 1998) Other authors have also investigated the label placement problem and its application in dynamic and interactive screen maps (Been et al., 2006, 2008; Mote, 2007).

van Kreveld et al. (1999) compared the use of a sliding model – where labels can be placed in an infinite number of positions – with the more commonly used discrete model. They stated that the use of the continuously sliding labels would allow more points to be labeled, both in theory and in practice. (Strijk and van Kreveld, 2002) Other heuristics which have been proposed include greedy algorithms, simulated annealing, tabu search heuristics, binary linear integer programming and other combinatorial optimization techniques (Christensen et al., 1995; Ribeiro and Lorena, 2006; Yamamoto et al., 2002; Zoraster, 1997).

Recently, a number of (user) studies have been conducted about the usability of interactive and dynamic web maps (Heidmann et al., 2003; Kramers, 2008; Ladniak and Kalamucki, 2007; Nivala et al., 2008), but none of these studies takes the label placement problem into account. The discussions about the user's cognitive maps, on the other hand, have focused on the distortions in these maps, usability issues in geovisualization, etc. (Montello, 2002; Portugali and Omer, 2003; Slocum et al., 2001). The influence of the different label placement options has so far been neglected. These influences are examined in the study described in this paper.

3 Study design

3.1 Method selection

From the long list of possible user study methods, the eye tracking method was considered to be the most suitable to get in touch with the user's cognitive processes during a visual search. This selection is based on the work of Rayner (1998) and Duchowski (2007), who expressed the close link between a person's eye movements and their cognitive processes. Henderson and Hollingworth (1998) also stated that the study of eye movement patterns during scene viewing contributes to an understanding of how the information is acquired and represented.

The eye tracking method has already successfully been applied in studies concerning human-computer interactions and usability research (Jacob and Karn, 2003). Recently, the method is also introduced in the field of cartography, both for paper maps (Brodersen et al., 2001) and map animations (Fabrikant et al., 2008).

The most commonly used measurements involve 'fixations' and 'saccades', from which a number of eye movement metrics are obtained (Table 1). These metrics give an indication about certain aspects of the user's cognitive processes (See Poole and Ball, 2006). Fixations can be defined as the locations where a user was looking. The saccades, on the other hand, are the eye movements between two such fixations. During a saccade, the user does not really see anything.
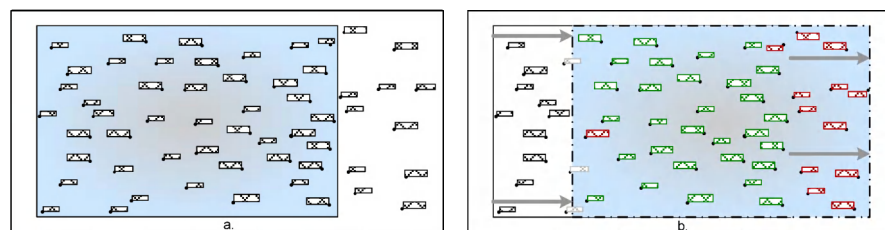
Measurement	Metric
Fixations	Duration; number overall; number per interest area; time to first on target; etc.
Saccades	Amplitude; number overall; etc.

Table 1: Eye movement metrics

Background data of the users is obtained by a questionnaire, which the user has to fill in after the actual assignment with the eye tracker. This complementary data is necessary to obtain insights in possible distortions or outliers in the data retrieved from the eye tracker. The content of this questionnaire is described in more detail in section 3.3.

3.2 Hypothesis

The hypothesis is related to the number of labels which have to be considered for relocation after a user interaction. The efficiency of the label placement algorithm or heuristic would increase drastically if fewer labels need to be considered in the calculations, regardless of the exact method which will be used in the end. As a consequence, the result is a major decrease in the computational costs, both in terms of time and memory.

The first hypothesis states that not every label in the view is considered for relocation after an interaction, but only those labels which have a high chance to become illegible due to the changes in the location of the view. These labels are thus situated at the border of the new view where:

1. certain labels will vanish or will be relocated;
2. certain labels will appear or will be relocated.

This is depicted in Figure 1, where a horizontal pan operation to the right is simulated. Figure 1a shows the view before the pan operation. Only the labels in red need to be considered by the label placement method after the interaction (Figure 1b). The black and grey labels disappear out of the view, whereas the green ones should remain in the same (relative) position.

Figure 1: Locations of the labels which have to be considered

The conducted tests check whether this intervention in the label placement methods has an effect on the user's cognitive map. If no interference is noticed, the label placement methods can be optimized significantly without disturbing the user's cognitive map. If, on the other hand, a positive influence is noticed, both the efficiency and effectiveness of the map towards the user will profit from it.

3.3 Structure of the study

During the tests, 20 different maps are presented to each user. The maps consist of a simple background with a number of point objects and labels on it. Initially, the map is presented for 50 seconds, allowing the user to locate five names on the map which are indicated in a list on the right side of the screen. After these initial 50 seconds, a user interaction is simulated on the screen, causing the view to slide to the right. In order to maintain consistency during whole the study, the user interaction is defined as a horizontal pan operation to the right (over a fixed distance). A new list of names is shown, from which three where already present in the previous list. Again, the user has to locate these names in the new view.

The movement of the eye is registered while the user executes the task. Furthermore, every time a name is found in the screen the user has to push a button. Only this way it can be verified if the user really found a label or if he was accidently looking over it. The combined data from the eye tracker and the buttons indicate which label was found and in what time interval.

After the user has finished his task on the eye tracker (and the 20 maps are thus processed), he is asked to fill in a questionnaire. This questionnaire allows retrieving background information about the user –general information, known areas, internet use, and feedback – which may explain deviation in the eye tracking results.

3.4 Pilot study

A pilot study was conducted at the end of 2008, using a reaction time measurement method to obtain preliminary results. In total 43 students were tested in the pilot study, from which 36 were first year geography-geomatics students and 7 were second year archaeology students. This resulted in 837 reaction time measurements.

The results obtained from this pilot study were used to get insight in possible weaknesses in the study design in order to enhance the main user study which uses the eye tracking method. The following adjustments were made to the structure of the study after interpreting the results from the pilot study:
-the time interval in which the initial view is shown is reduced from 90s to 50s;
-a simple background is added to the maps (which was not present in the original design);
-the questionnaire was modified at certain points.

4 Results

4.1 Subjects and the obtained data

The tests of the main study were executed in the Eye Tracking laboratory of the Faculty of Psychology and Educational Sciences from Ghent University. In total, 28 students were tested, from which 20 were psychology students (mainly from the first year). The other subjects originated from other faculties at the university.

4.2 Testing the quantitative data

At this stage of the study, only data related to the first hypothesis is available. The results derived from this data set are discussed in the next sections and are thus based on quantitative output from the eye tracker in combination with the reaction time measurement from the joystick. As both devices are integrated in one system and monitored by a single software package, the synchronization of both types of measurements is guaranteed.

Absolute reaction times

Firstly, the reaction times related to finding a specific label are examined. The observations are grouped by their type of map: Border and Total. 'Border' means that only labels near the border are considered for relocation; in the maps from the type 'Total' all the labels across the view are considered for relocations (see section 3.2). The table (Table 2) below presents an overview of the obtained results. This table clearly shows that none of the obtained P-values is below the 0,05 threshold, meaning that the values are not significant and the null-hypothesis thus can be accepted. This null-hypothesis states that no differences are noticed between both groups.

Time finding ...	...first label	...last label before the transition	... first label after the transition	... last label after the transition
Mann-Whitney U	*28243,000*	*24595,000*	*28121,500*	*26270,000*
Wilcoxon W	*57646,000*	*50473,000*	*58011,500*	*53298,000*
Z	*-,444*	*-,109*	*-,676*	*-,601*
Asymp. Sig. (2-tailed)	*,657*	*,913*	*,499*	*,548*

Table 2: Statistical output related to the reaction time measurements

Relative reaction times

Secondly, the relative values of these time measurements are tested. These relative values are obtained by taking into account that the names were subsequently located and correspond consequently with the time intervals between the localization of two subsequent labels. In this case, no division is made between the two types of maps as the former tests indicate that no differences are present in the measurements. The aim of the next tests is to obtain an insight in how users process and orientate the displayed initial map and simulated pan operation.

The mean ranks for the subsequent time intervals are depicted in Table 3, in which the numbers 11-15 are linked with the labels located before the transition and the numbers 21-25 to the five labels located after the transition. In this table the same trend is noticed before and after the transition: a longer time interval is associated with the location of the first label and the shortest with the location of the second label. After the second label is located the mean rank rises indicating an increase in the time needed to find each subsequent label.

Next, the Chi^2-test is used to investigate if the differences mentioned above are significant. For both parts (before and after the transition) the answer is 'yes', with $P<0,005$ ($Chi^2= 17,093$; $df=4$; $P=0,002$ and $Chi^2= 86,734$; $df=4$; $P=0,000$ respectively). With the aid of the Dunn test it can be determined which intervals are significantly different from each other. These tests reveal that in the first part only the second interval (related to label number 12) is significantly different from the first interval (11) and the last interval (15). In the second part more significant differences between the intervals are noticed: 21-24, 21-25, 22-24, 22-25, 23-24 and 23-25. The time interval related to the localization of label numbers 21 ,22 and 23 are thus significantly different from both 24 and 25. These findings also correspond to the results obtained during the initial pilot study.

orderLabels	N	Mean Rank		orderLabels	N	Mean Rank
11	486	1249,98		21	484	1120,17
12	475	1076,95		22	480	1056,99
13	483	1165,82		23	480	1155,41
14	468	1178,47		24	472	1306,03
15	439	1209,84		25	458	1306,91
Total	2351			Total	2374	
	(a)				*(b)*	

Table 3: Mean Ranks of the relative values; before (a) and after (b) the transition

	11	21	12	22	13	23	14	24	15	25
Mean Rank	552,88	417,85	513,83	442,54	520,22	443,54	478,94	462,13	462,98	435,60
P-values	0,000		0,000		0,000		0,343		0,114	

Table 4: Non-parametric tests on the corresponding intervals

Considering the fact that the same trend is observed before and after the transition, the differences between the corresponding intervals are analyzed. To accomplish this, the Wilcoxon W en Mann-Whitney U non-parametric tests are utilized. The results are shown in Table 4, which indicates that only the three first corresponding intervals differ significantly (with $P<0,001$). Although all other combinations are more alike (not significantly different, with $P>0,1$), a trend is noticed in the table. The mean ranks of the intervals which occur before the transition are in always higher than the corresponding intervals after the transition. This conclusion was also drawn from the data obtained during the pilot study.

Fixation count

In this section, some preliminary results linked to the registrations of the user's eye movements are presented. These results are derived from the number of fixations which are count during (a part of) the trial. This number gives an indication about the efficiency of the search: more fixations suggests that the search is less efficient (see Poole and Ball, 2006). A *t*-test is used to study these observations, with the different types of maps as grouping variable; the results are shown below in Table 5. The *P*-value indicates that there is no significant difference in the number of fixations between both groups (or map types) ($P>0,5$), which corresponds to the findings from the reaction time measurements.

	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
FixCount	0,464	425	0,643	2,575	5,554	-8,342	13,492

Table 5: t-test for Equality of Means for the number of fixations

5 Discussion

From our experiments, we may conclude that no (significant) difference in reaction time was observed between the two map types. This means that the search times for toponyms are not influenced by the type of map under consideration. Furthermore, the

set of the answers to the questionnaire revealed that none of the users noticed the differences between the two map types.

This leads to the conclusion that the efficiency of the label placement algorithm can be improved significantly – as fewer labels need to be considered –, without reducing the effectiveness of the map in conveying the message to the user. The user seems unaware of these adaptations, notwithstanding the fact that these adaptations influence not only the (non-visible) data structures and algorithm, but also label visualizations on the map itself.

The time intervals between the localization of two subsequent labels, on the other hand, provide insight into how the users orientate and search on a dynamic and interactive map. These values showed the same trend in the interval length before and after the transition, related to the location of the five names. The time necessary to find the first label is the longest, which could be explained by taking into account the user's need to orientate the map first before (s)he can start searching. After the transition, the first interval is smaller than before the transition, but still longer than then the second interval. The time needed to (re)orientate the map after the transition is thus less than when the initial view was presented. This is related to the fact that a part of the view after the transition was already visible before the transition and was consequently already known to the user.

The second label is localized in the shortest time interval, also both before and after the transition. At this moment the user has a clear overview of the map in his mind since (s)he has just finished the orientation process. The time interval slightly increases with the localization of the subsequent labels. This may indicate that the mental map obtained during the orientation process becomes less clear or correct over time.

The comparison between the corresponding time intervals before and after the transition revealed only three significantly different intervals, more specifically those linked with the first three labels. For these results, the mean rank of the intervals before the transition was significantly higher than after the transition. Although the other corresponding intervals showed no significant difference, the same remark can be made: the mean ranks before the transition are always higher than after. This may be explained by the fact that a section of the initial view remains visible after the transition. This means that the user already knows a part of the view after the transition, which facilitates his/her search.

That the two corresponding intervals linked with the fourth and the fifth label show no significant difference may be due to the fact that the cognitive map becomes less clear over time, both before and after the transition. This results in increased searching times which seem to stagnate at a certain point. In this case, this stagnation is visible with the fourth and the fifth interval especially after the transition. Consequently, the differences

in the searching times between the corresponding intervals diminish until no significant difference is noticed.

6 Conclusion

The results obtained from the study give an insight in how users perceive, search on, orientate and process certain information on a dynamic and interactive map. The study is organized in such a way that on the one hand, specific information related to the two posed hypotheses can be obtained. On the other hand, the study allows getting an insight in the user's general cognitive processes while working on a map; in this case while locating names on a dynamic map.

At this stage of the study it can be stated that the application of the first hypothesis improves the efficiency of label placement algorithms without having consequences on the effectiveness towards the user. Furthermore, the application of this method – with its consequences on the visualization of the labels – is not even noticed by the user. The information on how users orientate and process the information of the maps also allows the further improvement of the label placement algorithms and their effectiveness towards the user.

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