Evaluating the visual scanning efficiency of geovisualisation displays

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Introduction

One of the main tasks in designing geovisualisation displays is to find a balance between information density and potential need of information by users that allows for effective and efficient visual processing of the presented information. A plethora of technology-driven tools have favoured the presentation of huge spatio-temporal data on different kinds of displays. The underlying assumption for these complex geovisualisations is that users have sufficient cognitive skills for visually processing geographic information.

We argue, however, that a diligent design of geovisualisations that reduces the information complexity by incorporating the principle of relevance and a cognitively adequate presentation of the information should improve the overall utility and usability of geovisualisations. For that reason, we recently proposed the design approach of attention-guiding geovisualisation (Reichenbacher and Swienty 2007) following recommendations of prominent research agendas (Chinchor et al. 2005, MacEachren and Kraak, 2001) that revealed a lack of cognition-based research for developing scientifically testable visual representations of geographic information.

Improving visual scanning efficiency

Whenever users process geovisualisations they visually scan for relevant geographic information. Visual scanning describes sequences of gaze shifts during visual information processing and involves shifting of attention (accomplished by gaze shifts) as well as information processing (during gaze fixations). This cognitive skill of detecting and analysing relevant geographic information implies a cognitive workload that is characterised by investing a certain capacity of the limited attentional resources and that depends on the tasks imposed on the user's visual information processing system. The reduction of the cognitive load by means of a cognitively adequate geographic information design is a basic challenge of our work. Figure 1 illustrates a visual scanning efficiency model that tends to keep the cognitive load as low as possible by reducing the information complexity of geovisualisations to optimise the performance of users. Based on the performance-resource function (Norman and Bobrow, 1975) and the model of instructional efficiency (Paas et al., 2003) that consider the combination of low mental effort (little resources) and strong task performance as highly efficient, Swienty et al. (2008) regard the third axis of 'information complexity' as a determinant for relating basic parameters involved in the efficiency of visual geographic information processing.

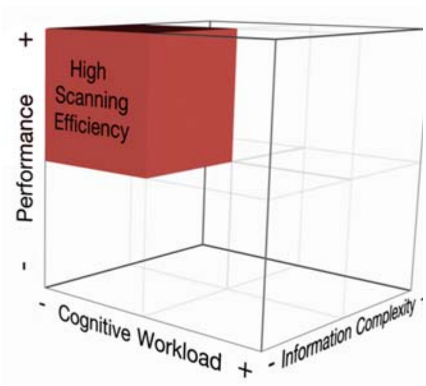

Fig. 1. Visual scanning efficiency

The axis 'information complexity' derives from psychological visual search tasks. If the slope of the reaction time (time required to affirm or negate the presence of an item) multiplied with the set size function (number of items on the display) is near zero, the efficiency of the task can be labelled as high and vice versa. With regard to visual geographic information processing 'information complexity' can be determined by complex visualisations (information rich geovisualisations) and complex visual scenes (stimulus rich environments), or by the combination of both. In other words, information-processing resources of e.g. explorative users can be overstrained by the representation of irrelevant geospatial objects on desktop displays. Due to the small display of mobile devices, gazes of mobile users can additionally be misguided by distractive stimuli that are located in geographic space. To reach high visual scanning efficiency we aim at keeping the visual scanning time (time needed to visually detect and decode the most relevant information) as short as possible by decreasing the number of information to the minimum without neglecting spatial context information needed to accomplish geographic tasks. Hence, information complexity is not objectively calculated like face, vertex and edge complexity measures. It is rather referred to as 'visual complexity' that can be regarded as the proportion of visually salient and visually lowered geographic information presentation.

Visual scanning is in a first step scene-based and not detail-based. Users process geographic information in a fast and global context-dependent manner before slowing down their scan path to a more detailed local mode of information processing (Torralba et al. 2006). In that order, the top-down processed base layer visualises the spatial reference in an unostentatious way to support users in maintaining a crude representation of geographic context information in the visual background for visual spatial orientation (global processing). The stimulus-driven bottom-up processed layer depicts relevant information in a salient way to support users in guiding their visual attention to relevant information (local processing). The combination of both layers generates an attention-guiding layer where relevance-based filtered information can be visually extracted from and related to the spatial context information.

In accordance with the visual scanning efficiency model, the attention-guiding design methodology aims at reducing information complexity and releasing the cognitive workload by filtering information based on their relevance and visually encoding the degrees of relevance with suitable visual variables. In the next section we present an evaluation of the two variables, value and size, for their ability to guide visual attention.

Evaluation

The evaluation applying the eye tracking method was conducted at the eye movement laboratory of the Max Planck Institute of Psychiatry in Munich. 15 untrained participants (5 male, 10 female) with a mean age of 28 years (range: 22-38 years) took part in the study. The used device recorded gaze fixations within a spatial area of 1° with a minimum duration of 100 ms.

To direct their visual attention to relevant geographic information users make use of specific saccadic eye movements like 'memory guided' saccades (to a cued location after delay) or 'voluntary' saccades (to a location without a visual transient). Bearing in mind that we aim at keeping the visual scanning time as short as possible in a first step, we focused on evaluating 'reflexive' saccades that are predominantly attracted by salient sensory input.

For a validation of the design methodology we designed three test cases: (1) unfiltered information is presented in a cognitively adequate way, (2) relevance-filtered information is presented in a cognitively less adequate way, and (3) filtered information is presented in a cognitively adequate way, i.e. an attention-guiding geovisualisation. The task for the test subjects was to scan for the relevant information that has been encoded as three point symbols and to confirm the detection of all three point symbols. In this work, we present the results of the evaluation where relevance classes of geographic information were coded with the variables *value* and *size*. The information of interest is highlighted with the larger circles. The small white circles represent single gaze fixations.

Fig. 2. Guiding attention with the variable 'value'. (base data are from Basis DLM of BKG, Germany; address data are from Städtisches Vermessungsamt Munich, Germany).

Figure 2 illustrates the visual scanning patterns of one test subject processing the three cases for the variable *value*. Table 1 shows the results for the variable *value*. Displayed are the mean values for the

measure time, scan path length (in degrees), number of fixations and re-fixations. To compare multiple means, an analysis of variance (ANOVA with Greenhouse-Geisser correction) was used. The values in brackets are the standard deviations. The value p in the last column indicates, whether the variations are significant.
Subjects needed the most time (11.07 sec.) to accomplish the task in case 1 due to the highest degree of scan paths (172.29) and the highest number of fixations (20.07). They employed 4.71 fixations to redirect their focus of attention. For case 2, the scan paths revealed a mean degree of 34.36. They needed 5.86 fixations and 2.55 seconds to accomplish the task. The most relevant information in the lower right corner was globally processed, i.e. the subject was not required to employ a gaze fixation to process this point symbol in detail. In case 3, the attention-guiding design, participants needed a mean time of 1.85 seconds by employing 3.79 fixations. Their scan paths revealed a mean degree of 23.12. The participants did employ 0.14 re-fixations to find the information of interest. The global mode of visual scanning was sufficient to detect all relevant point symbols.

Table 1. Visual scanning parameters when processing the variable *value*. σ (standard deviation), p (significance)

	case 1	case 2	case 3	p
time (σ)	11.07 (5.08)	2.55 (0.98)	1.85 (0.55)	<.001
degree (σ)	172.29 (114.09)	34.36 (12.52)	23.12 (9.47)	<.001
number of fixations (σ)	20.07 (13.27)	5.86 (2.32)	3.79 (1.58)	.001
repetition of fixations (σ)	4.71 (5.15)	0.36 (0.50)	0.14 (0.36)	.007

As a second visual variable capable of encoding ordinal data we tested was the variable *size*.

Fig. 3. Guiding attention with the variable *size*. (base data are from Basis DLM of BKG, Germany; address data are from Städtisches Vermessungsamt Munich, Germany).

Figure 3 illustrates the visual scanning patterns of one test subject processing the three cases for the variable *size*. Table 2 summarises the results for the variable *size*.

Table 2. Visual scanning parameters when processing the variable *size*. σ (standard deviation), p (significance)

	case 1	case 2	case 3	p
time (σ)	2.61 (1.20)	2.20 (0.61)	2.21 (1.08)	n.s
degree (σ)	29.20 (12.90)	28.47 (12.14)	24.51 (11.18)	n.s
number of fixations (σ)	5.07 (2.74)	4.07 (1.10)	4.60 (2.82)	n.s
repetition of fixations (σ)	0.40 (0.83)	0.00 (0.00)	0.20 (0.41)	n.s

In case 1, subjects needed only 2.61 seconds with 29.90 degrees of employed scan paths and 5.07 fixations. Almost no re-fixations were needed to redirect their focus of attention to relevant information. In case 2, the scan paths revealed a mean degree of 28.47 by employing 4.07 fixations. To detect relevant information in case 3, subjects needed a mean time of 2.21 seconds by employing 4.60 fixations. The mean degree of scan paths (24.51) was a little bit lower than in the first two test cases. To visually scan for relevant information in case 3, participants even accomplished the task without the need to position the gaze fixation on the relevant information itself. The primarily global mode of visual scanning was sufficient enough to detect the three point symbols due to the attention-guiding approach, i.e. participants did not invest more attentional resources to accomplish the task due to the well-structured and organised visual information. Although case 3 displays relevance filtered information and the design is based on the attention-guiding methodology the analysis revealed no significant differences between the three test cases.

Conclusions

The evaluation conducted served as a proof of concept for the visual attention-guiding approach discussed above and aimed at testing the performance of the visual scanning process for different geovisualisation designs and test subjects.

The analysis of the visual scanning parameters revealed a high visual scanning efficiency of users when processing the attention-guiding geovisualisations (case 3), i.e. users needed for both variables the shortest time, employed the least number of fixations with the smallest degree of scan paths. For the variable *value*, the case 3 was distinctly most successful and the variations in the means are significant. For the variable *size* the variations between the means for the different cases were not significant. If we compare the two tested variables for case 3 we see that the variable *value* scores slightly better. However, if this difference is significant has not been tested so far. The results indicate that the application of the attention-guiding geovisualisation methodology can improve the visual scanning efficiency and that it is capable of effectively guiding the visual attention of users to the location of relevant information. The test subjects detected the locations of the relevant items in the order of decreasing relevance. However, this fact does not necessarily imply that the underlying semantics of the relevance classes are understood by the participants and if, can be easily decoded by them. Users may be able to promptly locate the most important information and to relate this information to spatial dimensions. However, if the symbolisation is not appropriate to encode the semantics of the information, users have to employ more mental effort, which will decrease the efficiency of visual information processing.

Outlook

The results of our evaluation are promising, but are far from embracing the whole problem. Further research is concerned with testing more single variables as well as multiple encodings with respect to guide users' visual attention to locations of relevant information on displays. Furthermore, we will extend the evaluation and test the semantic dimension, i.e. if users additionally are capable of understanding the meaning of the detected information and decode their degree of relevance depending on the query to the system. We expect these tests will help to improve the visual scanning efficiency, as well as optimise the speed and accuracy of the overall visual geographic information processing.

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