Attention-Guiding Geovisualisation

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INTRODUCTION

The increasing amounts of geographic data available in recent times are visualised on a wide range of display sizes for variable applications. The basic challenge for designing geovisualisations (GeoVis) is the avoidance of too complex, too detailed and too dense visualisations. The objective is much more to allow users to quickly locate and easily decode relevant geographic information to make inferences.

Two examples of GeoVis that reflect very different notions of utilising visualisations to facilitate a user's decision-making process are mobile GeoVis and exploratory GeoVis. Mobile GeoVis services communicate known geographic information to individual users for private use with a low degree of human-computer interaction. In contrast, explorative systems reveal unknown geographic information for private use through high human-computer interaction. The small displays of mobile devices largely affect the visual information processing of users by distractive visual, auditory, and tactile stimuli (e.g. spot lights, car noise, rain) that are located in the geographic space (Reichenbacher and Swienty, 2006). Explorative users have to face a plethora of displayed information on desktops where the gaze is often deviated by the depiction of irrelevant geospatial objects, i.e. objects that yield no inherent information for the task at hand (Swienty et al., 2006).

However, success in both, information retrieval on small displays in mobile environments and exploratory data analysis on desktops in static environments are affected by selective visual attention, i.e. the ability to extract and recognise relevant information in visual scenes with high efficiency despite their complexity (Deco and Zihl, 2001). This work focuses on the development, application, and evaluation of attention-guiding GeoVis with respect to neurocognitive foundations of human visual information processing and relevance theory.

1. ACCEPTABILITY OF GEOVISUALISATIONS

So far, the practical acceptability of current mobile GeoVis services and GeoVis systems is still poor regarding the usefulness. According to Nielsen (1993), usefulness is one element of the practical acceptability of a system and composed itself among others of usability and utility. Both, utility and usability are underdeveloped in most mobile GeoVis services and geographic information systems (GIS) used for exploratory visual analysis. Here, we understand the relevance of information as an element of utility and the cognitively adequate visualisation as an element of usability. In mobile GeoVis services, a lack of context-awareness might cause the supply of information that is not relevant for the mobile user and has a direct influence on the usefulness of such services. At the same time, the extreme small map space challenges the attentional competition between processable visual information on the display and in the geographic space (visual environment). In exploratory GeoVis systems the visualisation of non-filtered spatio-temporal objects often causes overcrowded displays with highly detailed and dense information and complex relationships between objects. These visualisations have a distractive effect and interfere with the attentional capability of a user, i.e. they deviate the user's gaze from the information of interest.

The high quantity of data to be displayed in mobile and explorative GeoVis system implies a selection of relevant information to avoid a loss of utility caused by the presentation of irrelevant information. Accordingly, we separate irrelevant from relevant data by implementing relevance as a filter criterion in the request. The relevance feedback is represented by a 'visual relevance feedback', i.e. we embody and visualise relevance values as attributes of relevant geographical objects. The usability of GeoVis is enhanced by a cognitively adequate visualisation, i.e. the design methodology of GeoVis is strongly based on neurocognitive foundations and adapted to the visual information processing. Hence, we developed a visualisation, which stimulates the decision-making process by being adapted to the human ability of attentional visual information processing. GeoVis systems must support users in keeping their focus on the task with minimal distraction in operating the display. We believe, that the combination of a cognitively adequate visualisation (usability) and the separation of irrelevant from relevant information (utility) increases the overall usefulness and hence the practical acceptability of a GeoVis system.

2. VISUAL ATTENTIONAL PROCESSING OF RELEVANT INFORMATION

Users must be able to locate promptly and decode easily the information of interest to get visual awareness and to make inferences. These objectives are reflected in basic factors of visual attention. When processing geographic information on small displays or on larger desktop displays the attention of users is controlled by stimulus-driven bottom-up factors (e.g. sensory signals) and task-driven top-down factors (e.g. knowledge and prospects). The interaction of these factors generate eye movements according to where and what visual attention is paid to.

Visual attention is one category that describes the efficiency of mental processes. It corresponds to diverse capacities and processes that are related aspects of how humans become receptive to stimuli and how they may process incoming information. Attention is part of information processing, and contributes to mnemonic processes (Marocco and Davidson, 2000). Accordingly, attention is involved in selecting appropriate information, facilitating the storing and retrieval of information, monitoring executive activities (e.g. making inferences) by minimising responses to visual distractors, and maximising processing particular features representing targets. An important characteristic of attention is its limited capacity that can vary individually under diverse conditions (Ullman, 2000). Here, the focus is on 'selective visual attention', also known as e.g. 'visual exploration' which is the ability to recognise (highlight) relevant stimuli (relevant information) while suppressing competing distractors (irrelevant information).

The visual attention is connected to the amount of displayed information, which is in turn dependent on the selection of information based on relevance. In the domain of information retrieval, the term relevance stands for the quality of the response of a system with respect to the query. Relevance of information is never absolute, but rather expresses a relation to another entity. Saracevic (1996) classified such relations and differentiates the major categories of objective and subjective relevance. While objective relevance reflects the algorithmic determination of the relevance of information items with regard to the query, subjective relevance of entities is determined by the user's judgment and thus can be influenced by interfering factors. To classify relations of information Saracevic (1996) differentiated several dimensions of subjective relevance, e.g. topical, situational, motivational, and cognitive relevance.

In the fields of communication and pragmatics, Wilson and Sperber (2004) proposed the theory of cognitive relevance. This theory understands relevance as an assessment criterion for processable stimuli. Our approach to cognitively adequate follows this theory in the sense that attention-guiding GeoVis offers a visually encoded presentation of relevant geographic information consisting of stimuli that unify small effort (fast information localisation and easy information decoding) and high efficiency (e.g. generating inferences).

The assessment of relevance of geospatial objects is determined by the user's request and a so far unidentified number of contextual parameters. This assessment is a dynamic process involving a lot of overlapping relevance types, such as spatial relevance, temporal relevance or topical relevance. For instance, a mobile user who is looking for a cinema to watch a science fiction movie (topical relevance) does not necessarily choose the nearest cinema. The user might probably choose a late beginning of the movie (temporal relevance), because she has first a rendez-vous in a restaurant (activity relevance) that has to be close to the underground station (spatial relevance). Hence, it is not necessarily the closest cinema that is the most relevant, but rather the cinema that simultaneously combines all relevance types. Such an assessment combining different relevance types can for instance be achieved with a fuzzy set approach implementing spatial, temporal and semantic distance functions (see Reichenbacher 2007).

3. ATTENTION-GUIDING ATTRIBUTES AND GRAPHICAL VARIABLES

The effectiveness as an assessment criterion for attention-guiding GeoVis is reflected in the reduction of a user's cognitive workload, i.e. the increase in speed and accuracy when processing complex GeoVis. To reach this goal, cortical visual information processing pathways and corresponding areas must be stimulated to ease decision-making processes. If information can be localised rapidly (where) and decoded easily (what), more resources for decision making (how) and execution of movements (e.g. eye movements or clicking the mouse) are left. The stimulation of cortical areas that process the semantic content of information is reflected in the successful work of cartographers in the field of graphical semiotics. Here, the focus is on the stimulation of the 'where' processing pathway by (1) visualising the location of interesting information in a salient way, (2) by decreasing irrelevant information, and (3) by encoding the order of relevance in an easily processable way.

Findings from cognitive neuropsychology provide the theoretical basis for our design principles of attention-guiding GeoVis in mobile and exploratory systems. The basic aspect of the design methodology follows the centre-surround mechanism that implies the figure-ground segregation (Born et al, 2000). Hence, we design visualisations that attract human attention because of their saliency, i.e. focal (relevant) information that is silhouetted against the surrounded (context) information and is detected because of its salient stimulus.

Those stimuli are reflected in attributes that are assumed to be processed pre-attentively, i.e. these attributes can be detected rapidly and automatically without additionally demands on the attentional resources of users. Wolfe and Horowitz (2004) identified and ranked such attention-guiding attributes (e.g. colour or shape) and corresponding values (e.g. blue and rectangular) ranging from undoubted attributes to probable non-attributes due to their property to attract attention more or less effectively in visual search tasks. They consider *colour*, *motion*, *orientation*, and *size* as undoubted attributes and *luminance* (onset/polarity) and *shape* as probable attributes for the swift attraction of the gaze of users. Here, we exclude the attribute *motion* because our focus is on static attributes, but we stress that *motion* is faster detected compared to static attributes (Peterson and Dugas, 1972). Several dimensions of *motion* play a decisive role in attracting attention in GeoVis. Griffin et al. (2006) compared static small-multiple maps with animated maps. They state that animations are more appropriate to identify patterns, depending on specific pace and linearly moving cluster coherences of the Gestalt principle 'common fate'.

4. APPLICATION OF ATTENTION-GUIDING GEOVISUALISATION

The main design principle for our cognitively adequate GeoVis is the reduction of the quantity of visualised geographical objects, because irrelevant information has a distractive effect. At the same time, the reduced set of information items needs to be visualised in a salient way to support their functions as attractive stimuli.

The first step of our approach is the assessment of the relevance of the geographical objects in the information space. Such an assessment provides the base for filtering relevant information and reducing the amount of data. Furthermore, it allows for classifying the filtered geospatial objects into ranges of relevance. In a second step, the relevance-filtered geospatial objects are symbolised in the visual space. According the attention-guiding principle, these objects have to be visualised in a salient way. Their degree of saliency is dependent on the relevance value assessed before and represents a 'visual relevance feedback', i.e. we embody and visualise relevance values as attributes of relevant geographical objects.

The design approach follows the general methodology known from thematic mapping and subdivides the GeoVis in two visual layers. (1) According to the physiological centre-surround mechanism of vision, the visual background is reflected by the base layer. It depicts the context information and contains the spatial reference for the geospatial objects of relevance with regard of the user's query. This top-down processed information does not dominate the GeoVis, because it is sub-ordered to the main topic. (2) The bottom-up processed focal information is visualised in corresponding point-, polygon- and line-layers. These layers (and combination of these) are superimposed to the base layer and represent the focus of attention. Hence, the focal information has to be depicted in the most salient way by applying attention-guiding attributes. Attention-guiding GeoVis depicts both, the context and the focal information that has to be adjusted to the relevant geospatial objects. If the context information is not displayed salient enough, important geospatial information (e.g. landmarks) that is required for successful orientation and navigation in the physical space cannot be accurately perceived.

To study the proposed design approach we applied the steps explained above to two different test cases. The first test case simulates an exploratory geovisualisation environment applying the approach to ArcGIS. The geospatial objects are stored in a geodatabase where each object is assigned relevance class membership with a Visual Basic for Application (VBA) script. Furthermore, the script automatically changes the symbolisation of the objects by mapping the relevance class value stored in the feature attribute table to appropriate graphical variable values.

The second test case illustrates GeoVis for mobile services implemented with Scalable Vector Graphics (SVG). For a proof of concept, we compared three different design alternatives. The first alternative is a salient visualisation of geospatial objects that are not relevance-filtered. For the second alternative, we filtered the geospatial objects according to their relevance. However, we did not store the relevance value as an attribute of the objects and did not visually encode them. In the third alternative we both relevance-filtered the objects and encoded their relevance values with attention-guiding attributes in a salient way.

5. EVALUATION AND CONCLUSION

The evaluation of our proposed approach was conducted with a computational attention model (Itti et al., 1998) that has been successfully validated against experimental evidence for visual search tasks (e.g. Treisman and Gelade, 1980) and that served as a promising pre-evaluation method for eye-tracking studies (Fabrikant et al, 2006). The model is based on the centre-surround mechanism and predicts human gaze paths and fixations by extracting three pre-attentively processed attributes (colour, orientation and intensity contrasts). The results are encoded in three corresponding feature maps and synthesised in an 'attention map' that indicates the most salient regions in the GeoVis.

Our results reveal that a GeoVis with relevance-filtered objects, the encoding of the relevance as an attribute, and the salient visualisation of these objects are the most promising designs. The gaze paths and fixations on the bottom-up processed focal layer were not deviated by distractive stimuli on the top-down-processed base layer. Due to the cognition and relevance oriented design the attention model detects the class holding the most relevant objects in all visualisations.

However, as mentioned above conflicts regarding the saliency of the relevant objects and elements of the base layer may arise. For example, several GeoVis revealed that elements of the base layer may become too salient, e.g. due to bright colour hues. In this case, the predicted gaze paths are deviated to irrelevant information, because local contrasts of intensity in the context are too strong.

In this contribution, we investigated a purely bottom-up processed attributes with a computational model to guide attention of users to relevant information. We therefore concentrated on the stimulation of cortical areas that respond to the location of relevant information. As described, humans rely on task-influencing top-down factors, amongst others (e.g. goals, prospects, and expectations) on stored knowledge to navigate and orientate in the geographic space or to generate hypotheses. Therefore, we call for additional empirical studies that investigate (1) bottom-up and top-down processing of visual information and (2) provide quantitative data to judge the designed GeoVis.

Moreover, further research and empirical studies should investigate the human abilities of decoding the semantic content of existing symbols. Results from such studies will help to optimise the speed and accuracy of decoding the meaning, i.e. a stronger stimulation of the cortical 'what' processing pathway, and might help to design new symbols.

Furthermore, it is important to evaluate new graphical variables applicable to GeoVis. For example, the variable *motion* including its sub-dimensions is believed to attract and guide the attention of users to relevant information, particularly in the corner of a display (Bartram et al., 2003).
With regard to mobile GeoVis services, it is important to find out which stimuli and to what extent might deviate the visual attention of users from the display depending on specific dimensions of the geographic usage context.

To summarise, we expect that empirical studies in the mentioned fields and in depth cognitive-oriented design research will lead to the improvement of the usability (cognitively adequate visualisation) and the utility (separation of irrelevant from relevant information) and will contribute to the overall acceptability of GeoVis.

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