THE DEVELOPMENT OF EXPLORATIVE GEOVISUALISATION PROCESSES

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ABSTRACT

There is still a large capability discrepancy between humans and computers. To realise an intuitive data exploration it is necessary to draw human cognitive skills and computer efficiency together. This paper focusses on a interdisciplinary approach of the development of explorative geovisualisation methods that will support spatial data mining of high resolution remote sensing data. An approach for a conceptual framework of the development of explorative geovisualisation methods for displays is presented.

INTRODUCTION

In 2006 the high resolution satellite TerraSAR-X will be launched into the orbit to observe the earth’s surface in different kinds of operational modes for scientific and commercial utilisation. The Joint Research Laboratory (JRL) between Technical University of Munich (TUM) and German Aerospace Centre (DLR) is involved in a research project on “Automatical Image Understanding for High Resolution Remote Sensing”. The project which is subdivided into three interacting topics is supported by the German Helmholtz Association of National Research Centres (HGF). The JRL aims at developing novel algorithms for (1) InSAR image processing and (2) data fusion of multiple sensors. The Department of Cartography (LFK) will develop (3) multistrategical data mining techniques linked to explorative methods of geovisualisation.

Geographic Information Systems (GIS) are usually deployed to afford the acquisition, management, analysis and presentation of a well defined dataset. Earth observation data possesses a vast number of so far unknown information embedded in patterns and correlations of geographical objects and their attributes. Spatial data mining is a process of discovering hidden useful data and applies specific algorithms and techniques of geovisualisation to afford exploration. Using GIS as a platform for data exploration requires a high-level configuration of hardware and visualisation software to enhance the functionality of an information system.

A key point in data exploration is the intuitive searching process in a visualised environment which is closeley connected with cognitive processes. Thus, to allow users an intuitive navigation towards new interesting geographical information a user-interface must be created, which supports humans to make full use of their natural cognitive skills. Current function-rich user-interfaces of GIS are dominated by interactive brushing and statistic-oriented linking techniques, and by modified visualisation tools originated from explorative data analysis. However, they do not allow an intuitive exploration for specific users because they suffer from drawbacks which intersect the way of information processing. Explorative geovisualisation is a highly interactive process, characterised by a permanent clarification of the users information requirement [Elzer and Krohn, 1997]. Keeping this requirement in a constant and progressive way demands a well-engineered and retraceable way of information transmission.

An exploration-oriented display of information requires knowledge of the relation between geographical objects and their representation in the human memory. Therefore it is essential to analyse the process of vision and to integrate consolidated findings from physiology and psychology in the system engineering. The following sections presents an interdisciplinary approach for the development of explorative geovisualisation methods by relating aspects of cognition to aspects of engineering.
1. **THE TERM “EXPLORATIVE GEOVISUALISATION PROCESSES”**

Terms like “visual geodata mining techniques”, “explorative tools of geodata analysis” and “explorative geovisualisation tools” are often used to describe the process of exploring geographic informations stored in a database. The advantage of such phrases is that they can frequently be mentioned in a not defined context, but it may be problematic because it could lead to adopt them without any clarification.

Because of the novelty of the possibility to combine the visualisation of geographical information with data exploration it is favourable to deal with this subject in a descriptive way by relating it to a coupled process, a capability or an intitled model. “Geovisualisation is related to geoknowledge discovery since it often involves an iterative, customised process driven by human knowledge. However the two techniques can greatly complement each other” [Miller and Han, 2001]. “… a key feature of geovisualisation methods is the capability to explore geospatial data (to uncover hidden patterns and relationships in space and/or time); such exploration requires a high degree of interactivity not characteristic of traditional software for spatial data processing” [Slocum et al., 2001, p.2]. Plümer et al. [2001] have enumerated the main criteria of the “Visualisation in Scientific Computing” on a well shaped Internet page presenting a teaching module.

In this paper the term “Explorative Geovisualisation Processes” is used to present a model of the scope and the related working fields of their development. The denotation “Explorative” refers to an investigative behaviour. The frequently mentioned expression “Geovisualisation” depicts the representation of geographical information and “Processes” refers to interactivity. In a broad sense, an explorative geovisualisation process is a highly interactive process of making internal geographical objects and structures explicit in terms of communication, transformation, exploration, visual cognition, object recognition, and knowledge enhancement. It requires high-level configuration of hardware and visualisation software to develop methods to support users in exploring large datasets of geographical information.

All of these terms are related very closely to each other but it is necessary to first consider them in a separate way, and then to find out intersections and to optimise their connections. Communication refers to human-human and human-computer interactivity while transformation focusses on encoding and decoding information. Exploration as a searching process where information accrues stands for the intuitive navigation towards geographical information [Bates, 1986; Elzer and Krohn, 1997]. The information processing is embedded in the field of visual cognition and refers to the visual system, the visual perception, the processes in the brain system and the memory. Object recognition is a term which is deeply rooted in the field of visual cognition. The affordance to avoid ambiguous visualisation of geographic information by the display of a semantically well-associated symbol to the geographical object requires knowledge of the stages of processing in object recognition. Adapting the perceptual and semantic classification of an object to the optimised encoding and visualisation of pictorial semantics can help humans name “an object in sight” [Ullmann, 2000, p. 3].

The consideration of these terms in the development process leads to a shortened way from comprehension to decision making and render an automatic image understanding for high resolution remote sensing and data exploration to finally realise an enhancement of knowledge.

2. **CONCEPTUAL FRAMEWORK OF THE DEVELOPMENT PROCESS**

A conceptual framework of the development process is presented to outline the scope of the engineering process and to get an overview of the related working fields. Cartographers recognised centuries ago that mapmakers are in fact mind makers [Montello, 2002] and the steady advancement of hardware and visualisation software has given users nowadays the possibility to handle a vast number of geodata in a reasonable time. However, novel methods of geovisualisation will be of little use if cartographers do not notice methods and processes of the mental utilisation of maps. Thus it is advantageous to implement the knowledge gain of visual cognition and cognitive processing of visualised geoinformation in a conceptual framework. Many research and working fields have already provided numerous findings and reasoned approaches connected to the science of cognitive psychology. Their obligatory consideration affords an interdisciplinary approach.

2.1 **Development process of explorative geovisualisation methods for displays**

To assure the permanent enhancement of the effectiveness of displayed explorative geovisualition methods it is therefore favourable to design a circular model consisting of optimising components. Figure 1 shows the elementary stages of the conceptual framework of the development process involving elements of other research and working fields. Before focussing on the several stages of the development process a simplified explanation is given.
The two main sections are the geoexploration space and the development space framing a sequence of testing, configuration and evaluation methods which are affected by influencing elements and criteria.

The geoexploration space represents the field of activity in which a user is exploring geodata conditioned by visual cognition and memory processes whereas the development space is the area in which the engineer is developing novel methods also strongly affected by visual cognition and memory processes. The term “engineer” is named to emphasise the GIS engineering process. This model assume that nowadays cartographers are not only able to handle but also to configure a GIS. The information transmission results from an unsatisfactory standard of explorative Geovisualisation on the part of the user who then get in touch with the engineer. Once the engineer has given a feedback the bidirectional information transmission is opened and the analysis of the unsatisfactory standard is begins. The usability test has a very important function in the development sequence by finding out whether the system is comfortable to use and if it reacts satisfactorily to the users expected tasks. The testing mode is strong affected by elements determining the quality of performance on usability testing and by well defined exclusion criteria for test persons. Results of the test have a great impact on further steps of system configuration which is accompanied by a formative evaluation and terminates after a summative evaluation. Finally the implementation of the enhanced methods to the users system can be accomplished. To guarantee a permanent enhancement of the improved methods it is necessary to continue the development process by further research and an iterative approach of the explorative geovisualisation methods.

### 2.2 Cognitive and brain processes in the exploration process

The exploration process is taking place in the geoeexploration space. Elzer and Krohn [1997] and Bates [1986] give a detailed description of the exploration process and its character of a searching process. Their model serves to relate the attitude of searching to relevant cognitive processes. Figure 2 shows the computational exploration process in terms of visual cognition. The motive for the exploration of geographical information is a users problematic situation characterised by a changing standard of knowledge interacting with the information requirement. Exploration has nothing in common with the matching process.

A user working with a traditional GIS has a concrete imagination of what he is looking for and knows how to match the attributes to get a result. Which informations accords to the needs of the retrieval and which informations are received by the user is finally decided from the matching process. Therefore, traditional GIS are used to realise data acquisition, management, analysis and presentation of results. This principle is obviously insufficient for somebody who has a fuzzy imagination of what he is searching for.
The user has to develop an explorative behaviour which is characterised by a clarification and development of the information requirement during the searching process. Thus, the modified information need is embedded in the paradigm and considers that the searcher develops a different view of the problem. The human-computer interactivity is taking place between the information requirement and the data display consisting of sequences processing the visualised information. The effectiveness of exploration depends on the support of intuition during the searching process which is intimately connected to the time of information processing. To accelerate the information processing by realising a smooth information transfer it is helpful to answer the questions “How can an user interface be designed to support intuition ?” and “How well can a symbol semantically be associated to the geographical object ?”. Having a closer look to the visual system and the processes in brain areas interacting with object recognition helps to retrace the way of human information processing and to point out some findings which have to be carefully attended in the system engineering.

The human visual system consists of the eyes, parts of the brain and the pathways connecting them[Atkinson et al., 1990]. Humans who are looking at a display do not gather the information in a single way, because of the geometry of the field of view, consisting of a central system with a high sensitivity for details and a peripheral system with a high sensitivity for movements. Important displayed information could be placed in the centre of the vision field while signatures in the peripheral field of view (corners of a display) could be better designed with changing features to attract attention [Buziek, 2000]. Visual attention is unlike a camera which records everything it sees. The brain can only focus on one part of an image, as when you are looking into someone’s eyes and ignoring the rest of the features of the face. To conclude that changing features should only be placed in the peripheral field of a display to attract attention assume that a user can keep his eyes steady in the center of a display while moving his attention around. Corbetta and Shulman [2002] investigated the relationship of visual attention and eye movement by superimposing mapped brain regions that became active during shifting attention and regions that became active during eye movements. They found out that 60%-80% of the activated regions are the same. In other words, it could be favorable not to trust only on changing features to draw attention to an important information. Therefore, it could be problematic only to pay attention to the peripheral fields of a display in designing the user interface. If somebody is searching for information and focuses his attention down to the right side of the display he could lose important information in the center or top left of the display by scrolling or zooming the image. In summary it can be ascertained that current visual stimuli to foreground objects like movement, outline, shape, size, symbols like arrows, on/off effects, highlights, outline, oddity, icons, zoom and pan have to be more researched in the context of saliency in the peripheral field of view. Activating the echoic system by applying the stimuli sound can also help to draw the user’s attention to an unseen information unit and requires no additional hardware and software. The double encoding (visualisation and sound) of Information enables an optimised retrieval of information because both are stored in the memory.

The pathways connecting the brain are the extension of the retina consisting of rods, cones and ganglions which forms the optic nerve. Rods and cones determines our sensitivity to a lights intensity. Rods are sensitive for brightness and colours while cones are sensitive for darkness and greyscales. This is of course an old awareness, but it should be considered in the development of explorative geovisualisation methods because the ganglion cells are the last neurons in the chain, before the output leaves the eye and goes to the visual cortex. On the average there are more rods
connected to a single ganglion cell than cones do. Therefore rod-based ganglions gets more inputs than cone-based ones. The fact that more rods are connected to a ganglion cell than cones leads to the consequence that vision is more sensitive when based on rods than on cones [Atkinson et al., 1996]. Thus, highlighted information should be predominantly designed by using bright and colourful symbols to enhance visual stimulation.

The visual cortex consists of different areas which are processing the information coming from the pathways. The consciousness takes place in the visual cortex and it is at the same time a kind of distribution center. On one hand it is connected to the interacting memories and on the other hand it is involved in the Bottom-Up-Processing. Figure 3 shows the information processing that proceeds in a single direction from sensory input, through perceptual analysis, towards motor output without involving feedback information flowing backwards from already stored information [Corbetta and Shulman, 2002]. Adapting the abovementioned findings to the methods of geovisualisation helps to accelerate the time of information processing.

It is obvious that an intuitive navigation towards information only can happen by a smooth information transmission, so that it takes no more time than 180-260 ms before a relevant mouse-click. Therefore it is important not to overload information represented on the display and weaken the human information-processing capabilities. Humans can rapidly recognize $7 \pm 2$ so called chunks of information [Miller, 1956]. A chunk is the limited capacity of absorbing information by humans and can be hold in the short-term memory for 15 – 30 sec. The short-term memory processes perceptual input coming from the visual cortex while the working memory is a system according to temporary storage and information processing. It helps to solve problems and to generate and implementate solutions [Baddeley, 1986]. Even though humans are able to process a lot of information if they are familiar with the design of an interface it can happen that short-term and working memory are overloaded by “thick” user interfaces with overcrowded display of interactive windows and too many facts and decisions to solve a problem. Novices tend to work with smaller chunks until they can cluster concepts into larger ones but they could be limited in their learning aptitude by complicated guides characterised by time-consuming textual support.

“Short-term and working memory are highly volatile; disruptions cause loss of information, and delays can require that the memory be refreshed” [Shneiderman and Plaisant, 2005, p. 459]. Thus, the effectiveness of interactivity and in particular the success of an exploration process depends on the response time of the system. Supporting intuition in the searching process includes a reduction of delays because users are addicted to the pace of the interface. The fact that users use the short-term memory in conjunction with the working-memory in information processing and that these memories can be overloaded or unchallenged leads to the conclusion that short-term memory load should be reduced or aided.

Figure 3: Time of information processing in the Bottom-Up Processing

[Thorpe and Fabre-Thorpe, 2001]
Shneiderman and Plaisant [2005, p.75] include the reduce of short-term memory in their 8 golden rules of interface design and mention that it “... requires that displays be kept simple, multi-page displays be consolidated, window-motion frequency be reduced, and sufficient time be alloted for codes, mnemonics and sequences of action.” In contrary an unchallenged short-term memory also handicaps the clarifying of the user requirements during the explorative retrieval process, because of a reduced success in learning. To discover the intersection of reducing and unchallenging in the short-term memory smooth the way to the long-term memory where information is stored for a longer time. Inserting information in the long-term memory takes a longer time (about 8 sec.) than in the short-term memory (0.1-2 sec.) but information can be retrieved much faster. In addition, the capacity and the longevity “seems to be” unlimited. To enhance the flow from stored information to motoric action it requires a high interactivity between memory processes and object recognition. The Top-Down Processing conveys knowledge derived from previous experience rather than sensory stimulation [Corbetta and Shulman, 2002] to the working memory for decision making. A user recognising an object on the display by getting access to his long-term memory is able to more easily navigate in the geoexploration space than by consulting a legend. It is closely associated with the image query and image understanding functions concerning the optimised encoding and visualisation of pictorial semantics and the level of details of geographic information. There are different attributes which have to be considered in the semantic improvement of visualisation methods which are causes of a constricted communication. Besides actuality of representation, graphics connected to syntax, and sources of interference, the educational background [Hake et al., 2002] in terms of experience plays an important role in object recognition.

“Naming an object in sight” [Ullmann, 2000] requires on the one hand that the user has already stored the object information in the long-term memory. In other words, a user who is already trained in handling a GIS and exploring satellite images has recorded more encoded information than a “novice”. Therefore, the “expert” is able to decode already recorded object information faster than a novice. On the other hand, novices don’t have the educational background or experience to handle a GIS or to immediately navigate in the geoexploration space. To afford a fast absorption, processing and recording of object information it is necessary to find out how to design an object. In other words, how to adapt the recognition of large number of objects (shape-based recognition, recognition by image combinations, recognition by visual routines) to the presentation of large number of objects (from the representation of the reality up to a high-level encoded symbol). In this context it must be considered that there are already symbols (e.g. representing tools) with an ambiguous visualisation which do not need to be redesigned, because users have already recorded them in their memory and know its function and location on the taskbar, so that they click intuitively on it (Figure 4).

2.3 Bidirectional information transmission

The engineer is contacted by the user in the case of an unsatisfactory standard of explorative geovisualisation. This human-human interactivity implies a bidirectional information transmission which is not yet embedded in the development process. It is neglected that an engineer’s work is also intimately connected to visual cognition and memory processes. This sounds quite strange but there are a lot of ways to communicate with each other consisting of misunderstandings. Information transmission between both of them is meaningless if different educational and cultural backgrounds and exclusion criteria for usability testing are not considered. Consequently, exclusion criteria also have to be applied for engineers during the development process because it is meaningless to commission an engineer to develop cognitive oriented geovisualisation methods if he possesses cognition retardent criteria. The discrepancy between a user’s expectation of the system potentials and the engineer’s knowledge about what the user is expecting is still a critical element in the development of a system.

In this context it is not predominantly a hardware-based problem rather a software problem. There are already GIS which are able to handle several gigabites but a lot of GIS contain poorly conceived visualisation methods and low quality of software tools. The development of explorative geovisualisation methods affords a close collaboration between users and engineers because the quality of GIS enhancement begins with a well encoding and decoding of information transmission. A question like “How do I say, write or show something ?” must be considered in this teamwork, because it stimulates the whole development process.
2.4 Factors determining the quality of performance on usability testing

Usability testing has become more and more important in different working fields dealing with human-computer interactivity. In cartography, the methods of usability testing are not the same as usability engineering, a term used to describe methods for analyzing and enhancing the usability of software [Nielsen, 1993]. Therefore it is quite helpful, to adapt cartographers testing methods to well conceived usability tests from other working fields. The basis to design an explorative human-computer dialogue structure is dominated by cognitive issues such as attention, perception, memory, problem solving and decision making.

The development of explorative geovisualisation methods has the task to make the system easy to learn and easy to use, thus support intuition in the exploration of geodata. Therefore, it is helpful to learn from cognitive engineering methods which are involved in designing user interfaces with a high-level interactivity like interfaces for pilots in air planes. The cognitive engineering approach is different from the traditional HCI approach having its focus on the human-computer interaction as mediated by a computer rather than on the human-computer interaction. Cognitive engineering try to give answers to questions like “Which methods can facilitate the work of domain practitioners and helps to achieve their goals more effectively?”, “What are the goals and constraints in the application domain?”, “What range of tasks do domain practitioners perform?”, “What strategies do they use to perform these tasks?” and “What factors contribute to task complexity?” [Roth et al., 2002, p. 2]. Woods and Roth [1988] created the “cognitive system triad” a model which points out that three interconnected factors determine the quality of performance on a task: factors in the external world (challenges to be met), factors with human and machine agents (the expertise and sources of error of human and machine agents who act on the world), and factors with information representations (through which the agents experience and learn about the world). Figure 5 shows the elements determining the quality of performance on usability testing based on the cognitive system triad.

<table>
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<tr>
<th>factors in the external world/development process:</th>
<th>physical environment (data source), goal-means structure, complexity of task elements, interaction &amp; constraints</th>
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<td>strategies</td>
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<td>factors with information representations:</td>
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<td>visual form directability &amp; observability</td>
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Figure 5: Elements determining the quality of performance on usability testing

To implement knowledge of human information-processing characteristics, like how to attract attention to unexpected data, into principles and techniques for human-computer interface design we have to consider three interacting factors having influence on the quality of a usability testing. For example, factors in the external world determine the cognitive demands and the range of cognitive situations that users are likely to face in trying to perform domain tasks like interactions and constraints need to be considered in determining actions “like a small number of independent components are easier to control than are multiple, interdependent components” [Roth et al., 2002, p. 6]. Human or machine agents employ strategies to meet the challenges of the development process. Assuming a user who is highlighting an information or clicking on a certain tool we can design features that highlight areas of a connected information or highlight a linked tool which could probably enhance the users information need. The ways that the challenges of the development are represented by the the factors with information representation make it easier or harder to meet them. In other words, factors with information representation can make solutions to problems transparent or difficult to see by providing affordances. Finally we can see how agents interact with current and new artifacts in order to better understand the demands of the development that have to be better met.
2.5 Exclusion criteria enhancing the quality of usability testing

Testing the usability of cognition-oriented methods requires the exclusion of test persons who possess cognitive dysfunctions to get a homogeneous and evaluable data collection. “Cognitive dysjunctions” is a broad collective term and involves all mental dysjunctions like people having a down-syndrom, dyslexia, dementia of all ages, people who are depressive, achromates etc. Their exclusion is essential because they could have an extremely understated short-term memory or stereoscopic vision. Two examples give a review to underline the importance of this subject: Achromates, people who are colour blind, have a natively heritable defect which concerns 1 of 12 men (global, 8%) and < 1 of 200 women (global, 0.5%). There were about 550.000 germans who were visually handicapped (StBa, Federal statistical office in Germany) in the year 2002 [http://www.destatis.de/]. The German National Health Interview and Examination Survey (GHS) investigates the prevalence of somatic and mental disorders in the general adult population in Germany, aged 18-65. Mental disorders are highly prevalent with a lifetime prevalence of 43%. Anxiety disorders, mood disorders and somatoform syndromes are the most frequent diagnoses [Jacobi et al., 2004]. These two statistics shows the high percentage of persons having cognitive dysjunctions and how helpful it can be to design a standardised exclusion criteria catalogue adapted to the development of explorative geovisualisation methods.

2.6 System configuration and evaluation

The system configuration and evaluation is based on the issues in the previous sections and is geared to the results of the usability test which is again influenced by elements determining its quality of performance. Therefore, the approach of an effective system configuration and evaluation is highly characterised by a cognitive-oriented research in the exploration process. Understanding how humans represent geoobjects in their mind, researching on how information must be encoded to be easily decoded, retracing the long and complicated way of information processing in human brains to accelerate information processing, and joining these findings to the results of the usability test stimulates the configuration and evaluation of explorative geovisualisation methods. Evaluation and usability testing are longsome and sensitive elements in the engineering sequence. If we can develop an exclusion criteria catalogue we can minimise the time for user testing and optimise the evaluation process. There are a lot of evaluation versions (Query methods, etc.) involving legitimated questions like how to measure usability. However, testing and evaluating a cognition-oriented information system requires to distinguish between what testpersons think and say and what they actually do. Thus, we have to match the evaluation aspects target (user, system), type (formative, summative), measure (usability, satisfaction) and methods (eye-tracking, interviews, log in etc.) to create a cognition based framework with the character of a cognitive walkthrough. Figure 6 shows some cognitive-oriented issues during the users retrieval and their relationship to aspects of system adaption.

![Diagram of system configuration and evaluation of explorative geovisualisation methods](image)

The users structure is characterised by his needs and tasks which are related to cognitive activities during retrieval, highly depending on the data content and the structure of the data base while the evaluation of the queries during the retrieval decisions is focussed on the indexing and encoding methods to get conclusions of the optimised encoding and visualisation of pictorial semantics.
To evaluate search strategies is to identify the content of communication in user system-interaction and to analyse information strategies applied by users during decision making. The intuitive search strategy is embedded in the exploration process supported by a combination of data mining algorithms. Finally, the evaluation of the interface for explorative geovisualisation is an identification of the form of interface communication by relating this to the users learning process. The other way round, the analysis of users cognitive resource profiles is necessary to adapt the resource requirements to the interface. Regarding the training of cognitive skills a focus on the level of expertise and the performance criteria is important to adapt the user interface to the users cognitive skills. The evaluation should be rendered flexible enough to cope with the wide range of users with more or less explorative needs and intentions.

The goal of the summative evaluation is to measure the value of the visualisation of explorative geovisualisation methods in terms of efficiency, effectiveness and subjective satisfaction as variables for navigation towards information. Efficiency is determined by the time users spent to find information and the time the system needs to react on queries while effectiveness is determined by the completeness and accuracy with which users achieve their task goal. Subjective satisfaction means attitudes toward the use of methods. It is quite an important value, because satisfaction leads to motivation and results. With regard to the development process, we have to concern that further research leads to an iterative enhancement of explorative geovisualisation methods and that the development of explorative geovisualisation methods is a never-ending process.

3. CONCLUSION

The previous sections have presented an interdisciplinary approach of a model of development of explorative geovisualisation methods by relating aspects of cognition to aspects of engineering. Explorative geovisualisation methods for displays need to be developed in a conceptual framework which involves the knowledge gain of visual cognition and cognitive processing of visualised information.

It is needless to note that nowadays an adaption of the computer’s time of data presentation to the humans’ time of information processing is impossible because of to long loading time of data and limited display rates. However, we have the possibility to design a GIS interface which bridges this discrepancy. Visual attention is controlled by both Top-Down factors, such as knowledge, expectation and current goals, and Bootom-Up factors that reflect sensory stimulation. Factors such as novelty and unexpectedness, results from an interaction between cognitive and sensory influences. The interplay of these factors controls where, how and to what we pay attention in the visual environment. Therefore, further research in adapting the interaction of cognitive Top-Down and Bottom-Up processes to the development of explorative geovisualisation methods needs to be done.

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