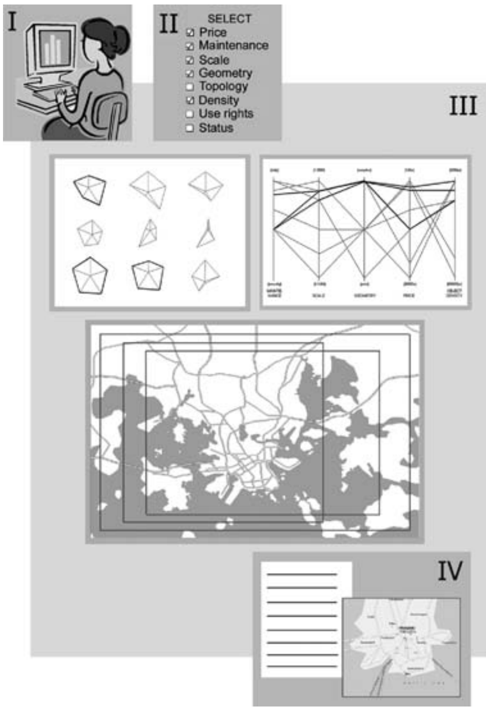
Section E
Making Useful and Useable Geovisualization
Design and Evaluation Issues



J. Dykes, A.M. MacEachren, M-J. Kraak (2005), Exploring Geovisualization, Pergamon, 732pp. 0-08-044531-4

Exploring Geovisualization
J. Dykes, A.M. MacEachren, M.-J. Kraak (Editors)

Chapter 28

Making Useful and Useable Geovisualization: Design and Evaluation Issues

Sven Fuhrmann, Department of Geography, GeoVISTA Center, The Pennsylvania State University, 302 Walker Building, University Park, PA 16802, USA
Paula Ahonen-Rainio, Institute of Cartography and Geoinformatics, Department of Surveying, Helsinki University of Technology, PO Box 1200, Espoo, FIN-02015 HUT, Finland
Robert M. Edsall, Department of Geography, Arizona State University, PO Box 870104, Tempe, AZ 85287, USA
Sara I. Fabrikant, UC Santa Barbara, Department of Geography, 3611 Ellison, Santa Barbara, CA 93106, USA
Etien L. Koua, Department of Geo-Information Processing, International Institute for Geo-Information Science and Earth Observation, PO Box 6, 7500 AA Enschede, The Netherlands
Carolina Tobón, University College London, Centre for Advanced Spatial Analysis, 1-19 Torrington Place, Gower Street, London WC1E 6BT, UK
Colin Ware, Center for Coastal and Ocean Mapping (and Computer Science Department), University of New Hampshire, 24 Colovos Road, Durham, NH 03824, USA
Stephanie Wilson, Centre for HCI Design, City University, Northampton Square, London EC1V 0HB, UK

Keywords: usability, usefulness, user-centered design, human–computer interaction, geovisualization

Abstract

The design of geovisualization tools is not only a technical research question. For many years geovisualization tool design was largely technology driven, where system designers and final users were mostly one and the same. Nowadays geovisualization tools are applied in and developed for a broader geosoftware market with the goal of providing useful and usable geovisualization. Sometimes this goal is not reached for many reasons, resulting in frustrated users and unsolved tasks. The aim of this overarching chapter is to give an introduction into methods and research questions on user-centered geovisualization tool design, bridging the gap between developers

J. Dykes, A.M. MacEachren, M-J. Kraak (2005), Exploring Geovisualization, Pergamon, 732pp. 0-08-044531-4

and users. In order to stimulate the development of geovisualization theory, the authors of this chapter contribute their views and discuss issues from Computer Science, Information Visualization, Geoinformation Science, Geography and Cartography.

28.1 Introduction

Influenced by recent developments within the Human–Computer Interaction (HCI) community developers of geovisualization environments are becoming increasingly concerned with the usability of their tools. Some of the key questions are whether geovisualization approaches are indeed effective for spatial problem solving, and if the novel tool designs are actually usable and useful for knowledge discovery and decision making? From a research perspective, geovisualizers have become interested in borrowing HCI approaches and applying them to their visualization efforts, as to ensure the usability of their geovisualization tools before they are released (Slocum et al., 2001; Fuhrmann, 2003). It has become clear, however, that constructing effective geovisualization tools and designing novel graphic displays is not just a simple matter of knowledge transfer from HCI to geovisualization. The questions "what can the relatively new field of geovisualization learn from HCI research?" and "how to design useful and useable geovisualization?" reveal a range of multi-disciplinary research issues that will be highlighted in this and the following chapters.

The International Organization for Standardization (ISO) defined "usability" as "the extent to which a system can be used by specified users to achieve specified goals with effectiveness [the extent to which a goal is reached], efficiency [the effort to reach goals], and satisfaction [the user's opinion on system performance] in a specified context of use" (ISO 9241-11, 1998). This definition may be of benefit when identifying assessment measures of system usability (e.g., how fast a user is able to perform a task), but it might be too vague when assessing whether and how a tool can help solving a particular research problem. The ISO usability definition is mostly grounded in HCI and ergonomic workstation design research (Dix et al., 1998). In HCI, primary attention is often given to the optimal modeling of a system. In geographic, statistical, and information representation, the focus is more on the design of a representation to support the analysis of phenomena represented. Mark and Gould (1991) cited this distinction over 10 years ago, just as designers of GIS began considering HCI research:

> "Instead of interacting with a computer peripheral or its user interface, GIS users should be able to interact more directly with geographic information and geographic problems. A focus on human–problem or human–phenomenon interaction will better enable design and implementation of optimal user interfaces for GIS and related software".

Over the years, usability engineering has provided a wealth of usability assessment methods for components and tools (Nielsen, 1993). Currently, the application of these methods is intensified in geovisualization design and developers

J. Dykes, A.M. MacEachren, M-J. Kraak (2005), Exploring Geovisualization, Pergamon, 732pp. 0-08-044531-4

need to be aware that these often system-focused HCI methods might not distinguish between useful and usable. On the one hand, a geoscientist may argue for the parallel coordinate plot (PCP) as a useful approach to extract discrete multi-variate structures from a multi-variate geographic dataset. On the other hand, it may not be usable for a novice, because of its apparent semantic complexity, due to its novelty, and because of its graphic limitations such as overplotting. Although usability engineering partly borrows empirical principles and approaches from cognitive psychology (Lewis and Rieman, 1994; Landauer, 1995), its goals are typically of pragmatic nature. Usability evaluation is often restricted to an assessment of how well users may master a series of known or defined tasks with a particular interface component or tool, and/or are able to understand the conceptual model of a system to achieve the goal. It has been shown that user effectiveness, efficiency, and satisfaction measurements retrieve important usability information if the tasks for reaching a goal are well defined (Nielsen, 1993; Lindgaard, 1994). Operating airline booking systems or ATMs are examples of well-defined task structures. The user needs to proceed in predefined steps to retrieve a ticket or money from a system. Thus, usability evaluation uses the characteristics of the defined tasks and often applies detailed scenarios to measure users' successes in working with computer-based tools. In geovisualization, however, abductive data exploration and knowledge discovery use scenarios are typically ill defined, thus goal achievement becomes difficult to measure. We need to assess additional (mostly qualitative) information and ask: Is this user interface or tool useful? does it support the users' ability to understand the characteristics of the data represented? Does it allow new information to be extracted or spatial problems to be solved by interacting with the data? Thus, usefulness is often hard to measure quantitatively. In geovisualization, it expresses how well, for example, a geovisualization tool supports users in generating an appropriate model of the geospatial structure or phenomenon being investigated and to solve a research problem.

The relationship of users' individual differences, such as their cognitive abilities, their socio-demographic profile, their individual knowledge base (e.g., background and training), and their understanding of the underlying depiction framework embedded in geovisualization tools is often not systematically assessed with usability engineering techniques during tool development (Slocum et al., 2001). When evaluating geovisualization tools it is sometimes difficult to clearly distinguish between usability engineering for improving the design of a tool, from formally testing a theoretical framework employed for depiction.

Evaluating existing geovisualization tools or components on their usefulness and usability can only be considered as one part in the geovisualization tool design process. Often, "last minute" evaluations of software tools reveal major flaws that might bring a project back to its early conceptual stages. In order to avoid timely and costly tool developments, approaches to user-centered design are undertaken that utilize usability evaluations at an early stage. Efforts towards user-centered geovisualization design and elevation methods that can accompany the complete development cycle to ensure usable and useful geovisualization tools are introduced in §28.2 and §28.3.

J. Dykes, A.M. MacEachren, M-J. Kraak (2005), Exploring Geovisualization, Pergamon, 732pp. 0-08-044531-4

28.2 User-Centered Design Approach to Geovisualization

The development of geovisualization tools has often been limited to the domain of research, and frequently the system designer and the final user have been the same person: the innovator. Norman (1998) notes that in any domain each of five possible users categories – innovators, early adopters, pragmatists, conservatives and skeptics – have specific preferences and goals that need to be considered when designing software. Currently, geovisualization tools are evolving from the instruments developed by innovators and used by early adopters to the broader audience of pragmatists and conservatives and the range of possible user domains and tasks should be reflected in their design. Geovisualization designers are aware of some of the issues this may raise and have began to address them as discussed above and in Andrienko et al., this volume (Chapter 5).

In retrospect, geovisualization tool development, as well as other interactive software development, has been largely technology driven. Software engineers have defined concepts for tools following the latest possibilities of technology. With finished concepts in mind, they approached users in order to study their tasks and requirements that could be met with the tools to be designed. More recently, a paradigm shift towards user-centered design has occurred and methods have been developed involving user participation from the concept design stage of interactive software development, for example, (see Fuhrmann and Pike this volume (Chapter 31)), Ahonen-Raino and Kraak this volume (Chapter 32), Tobón this volume (Chapter 34), etc.

Modern user-centered design approaches of usability engineering integrate user domain and task reflections, aiming at usable and useful systems. Most user-centered design approaches are built on theories of cognitive psychology and social sciences

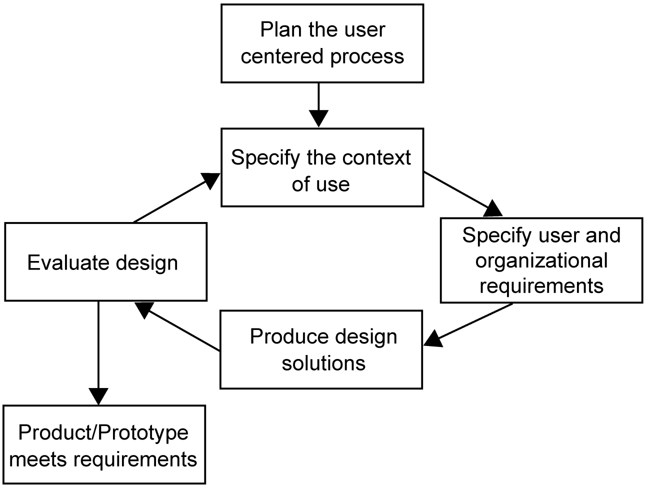


Figure 28.1. The user-centered design process (Bevan and Curson, 1999).

J. Dykes, A.M. MacEachren, M-J. Kraak (2005), Exploring Geovisualization, Pergamon, 732pp. 0-08-044531-4

(Hackos and Redish, 1998; Dix et al., 1998), and are under continuing development (Hassenzahl, 2001; Lewis, 2001). Usually, a user-centered design process (Figure 28.1) involves principles that can be described as:

- set an early focus on users and tasks;
- apply iterative and participatory design;
- measure the product usage empirically through user testing;
- modify the product repeatedly (Gould and Lewis, 1987; Rubin, 1994).

28.2.1 Focus early on users and tasks

One way of setting an early focus on domain users to gather more information is by utilizing the user analysis – an "activity of getting to know the characteristics of people who will later use the software" (Henry, 1998). A user analysis determines several characteristics, for example terminology, task expertise, disability and computer literacy of users and integrates domain expertise into the design process. Methods of learning about users and their needs that could be applicable to geovisualization tool design include unstructured and structured interviews about work situations and attitudes (questions and their sequences are either predetermined or not) and participant observations where users are monitored while archiving a particular working goal (Beyer and Holtzblatt, 1998).

Besides user characteristics, the range of domain-specific geovisualization goals and tasks needs to be considered. In general, geovisualization goals can be broken down into four categories: data exploration, analysis, synthesis and presentation (MacEachren and Kraak, 1997; Gahegan et al., 2001; (see also Gahegan, this volume (Chapter 4)). These geovisualization goals can be achieved through a series of tasks, subtasks, decisions, and constraints. For presentation purposes, tasks and goals can often be predicted during system design whereas the range of tasks and their application in exploratory geovisualization are often unpredictable (ill-defined), requiring more flexible systems. Thus, geovisualization tool design ideas should be based on context of use rather than on what is technically possible. This is particularly relevant when the instrument designed is intended for domain users rather than as an innovator's proof-of-concept in order to assure that the design concepts effectively support users' work processes.

Context and tasks of domain users are usually assessed with a task analysis. A task analysis is "the breakdown of overall tasks, as given, into their elements, and the specification of how these elements relate to one another in space, time and functional relation" (Sheridan, 1997). It is a multi-disciplinary method that supports evaluating HCI in terms of actions and cognitive processes in relation to user specific goals. About 25 different techniques can be applied during a user task analysis (Kirwan and Ainsworth, 1992). Here we cannot highlight the techniques in great detail, but can list and characterize the most common used for:

- task data collection (techniques that are used for collecting data on human-systems-interactions) and;

- task description (techniques that structure the information collected into a systematic format).

Informational and survey interviews are two inexpensive interviewing methods for task data collection (Kirwan and Ainsworth, 1992). Informational interviews are set up to collect a wide range of information on a task situation, while survey interviews have a more specific objective; they may for example review just one task in detail. The main advantage of the method is its natural and direct approach towards the user. In comparison to questionnaires, interviews are flexible. Important information can be documented quickly and later analyzed (Kirwan and Ainsworth, 1992). Since the participant can be highly influenced by those conducting the experiment, the social, interpersonal interaction also contains some limitations (Dix et al., 1998).

An alternative method of querying the user is to administer a questionnaire. A questionnaire usually contains a set of predetermined questions and is typically answered in a fixed sequence (Kirwan and Ainsworth, 1992). Questionnaires can be applied during different stages in user-centered design: for example, to find out about tasks of a user group or to measure user satisfaction at the final stage in the designing process (Nielsen, 1993). In addition, questionnaires can be used to reach a wide user group but they are inflexible when compared to interviews since the questions, and more importantly most answers, are fixed in advance. These answers might be restricted to the knowledge of the researcher and diverge from users needs. However, answers of closed questions can be analyzed more rigorously and allow the processing of many responses (Nielsen, 1993; Dix, et al., 1998).

In order to include a more user- and use-oriented perspective during geovisualization tool design, scenarios (Kuutti, 1995; Hackos and Redish, 1998) have become a popular method during user-task analysis. Carroll (2000) describes scenarios as "stories – about people and their activities". Usually these stories consist of user-interaction narratives, which are descriptions of what users do and experience as they try to make use of hardware and software (Kuutti, 1995). These user-interaction scenarios are a sophisticated medium for representing, analyzing and planning ways in which new hardware or software might impact user's tasks and experiences (Carroll, 1997). Most importantly, the vocabulary in these narratives is rich in actions, objects and metaphors, supporting their identification and incorporation into user interface design (Fuhrmann et al., 2001).

28.2.2 Describing tasks and concepts

Hierarchical task analysis (HTA) takes the results of the above task data collection techniques and describes the identified tasks and goals, placing emphasis on human abilities and system usability. HTA is directed towards decomposing a process into a hierarchy of operations and plans with instructions and constraints. Operations describe the basic tasks and subtasks of users, while plans display the condition statements that are necessary to execute operations (Dix et al., 1998; Hackos and Redish, 1998). The HTA can be graphically represented as a hierarchical diagram or in tabular form (Shepherd, 1995). In user interface design, HTA has many advantages because it is an economical

J. Dykes, A.M. MacEachren, M-J. Kraak (2005), Exploring Geovisualization, Pergamon, 732pp. 0-08-044531-4

method for gathering and organizing processes. In addition, it focuses on specific tasks within the context of an overall goal (Kirwan and Ainsworth, 1992). Since HTA identifies known tasks, ill-defined tasks, such as the goals of data exploration, might not get recognized. This limitation needs to be accounted for when applying the HTA during a user interface design process.

The shortcoming of describing ill-defined tasks for exploratory geovisualization might be overcome with the help of more participatory design methods. In order to achieve this goal, close contact between users and designers is emphasized in understanding the future context of tool use. Descriptive information acquired from users tends to generalize details that may prove to be important in design. Methods such as story telling have been developed to address this (Hackos and Redish, 1998; Erickson, 1995). In story telling, users are asked to recount and describe critical incidents that they recall related to the particular phenomenon under study. Stories give subjective, ambiguous and individual user views but as such they can be a valuable consideration in any design process of an exploratory nature. They may reveal more information about users and their sophisticated and sometimes abstract needs than generalized, objective descriptions (Erickson, 1995).

One of the challenges in designing geovisualization tools through user-centered methods is often the generic nature of the tools. The motivation for designers to invest in user requirement studies may be limited by the fact that intended users of the tools are frequently an ill-defined set of individuals. Even in this scenario, a designer would be advised not to operate at the "general user" level but to sample different geo-domain users in order to obtain different elements of input to the context of use and user needs. However, user-centered design methods are often criticized for being time consuming (Nielsen, 1993), since involving users in the early design process stages increases the complexity of the design task.

The benefits of an early emphasis on usability evaluation are discussed in §28.3 as various methods can be used and adapted to obtain information about a broad range of system and user aspects.

28.3 Dimensions of Geovisualization Evaluation

As part of the aim to make users the focus of the design cycle, the geovisualization community recognizes the need to evaluate its artifacts, yet the goals of such endeavors are not always clear. A fundamental driver of any evaluation activity is to identify aspects of a system that are less than optimal and have the potential to be improved in a redesign effort. Hence the importance of asking ourselves "why are we evaluating?" and "what is the purpose underlying the evaluation?" Within the field of HCI, this type of formative evaluation is commonly carried out by usability practitioners as part of ensuring the usability of interactive systems. Usability evaluation allows us to obtain data, often quantitative, about aspects of a system or the users' performance with that system that may be used for identifying aspects that are problematic for the user and to highlight potential fixes. These methods can also be used for comparison purposes, for example, against established benchmarks or against alternative designs or products, in order to

J. Dykes, A.M. MacEachren, M-J. Kraak (2005), Exploring Geovisualization, Pergamon, 732pp. 0-08-044531-4

identify which is easier to use or to learn, or to identify their relative advantages and disadvantages.

Usability evaluation, however, can also be more exploratory, reflecting the nature of geovisualization. This purpose is to understand more about users' tasks and goals – how and why they are employing geovisualization. Hence, evaluation can contribute to the understanding of research questions such as the type of tasks geovisualization systems should support. Clearly, the eventual goal here is to provide better support for the users' work, so this is closely related to the improving of systems. In practice, evaluations may be multi-facetted, serving several of the purposes listed above.

28.3.1 Dimensions of usability evaluation

The aim of evaluation may vary depending on the stage of the design and system lifecycle at which the evaluation is conducted. For instance, usability evaluation can be conducted to investigate a concept to be embedded in the design or it can be part of the implementation process. In general, usability evaluation investigates the functionality of the tool in terms of its ability to support user tasks, examines the interface in terms of how its features support user tasks and needs and assesses the way the tool accommodates different user operations. But it can also involve other aspects of the design and use of the artifact such as its effectiveness or perceived user satisfaction, which may be assessed against some level of expectation. These three dimensions of usability evaluation are considered here: the stage of the development cycle where the evaluation is conducted, the artefact to be evaluated, and the approach used to evaluate the tool.

The stage where usability evaluation takes place

One dimension of usability evaluation is the stage at which it is conducted. Depending on the stage in the system lifecycle, the evaluation can be carried out on a design concept, a design specification, a prototype or a fully functional system. It can be conducted as part of the design and development cycle, as a test during implementation or as a final assessment to understand the behavior of the tool and the users.

In the early stages, the main purpose of an evaluation is often to examine the effectiveness of preliminary design concepts. For example, while designing geovisualization tools for a specific user domain, the contextual limitations may be revealed at the concept design stage through scenarios or paper prototypes. These fairly simple techniques allow communicating design concepts to users at a draft level. Erickson (1995) states that working prototypes should be at a level of robust drafting to encourage users to give feedback to designers at an early stage. The "low-fidelity" prototypes may be constructed from standard office materials and then used where a member of the design team manipulates the prototype in response to user actions in order to convey the interactivity of the system. This technique elicits user feedback at low cost and without interference from detailed considerations such as graphic design.

J. Dykes, A.M. MacEachren, M-J. Kraak (2005), Exploring Geovisualization, Pergamon, 732pp. 0-08-044531-4

In later stages of the development cycle, usability evaluation can be conducted to assess the usability of the product itself. This type of usability test may again be formative, focusing on usability problems, such as effectiveness and efficiency that can be detected by expert users through techniques such as heuristic evaluation (Nielsen, 1993), or it may assess how the product compares to some predetermined usability standard. In the latter case, the test objectives are related to performance criteria such as speed and accuracy, how well and how fast the user can perform various tasks and operations, and how well all the components of the product work together. Techniques such as logging, which involves the automatic collection of statistics about actual system use, are helpful for gathering detailed data of how users perform their work once a system or prototype has been developed.

The artifact to be evaluated

The second dimension, related to the above, is the nature of the artefact to be evaluated. It is not necessary to have an interactive, fully functional system to conduct an effective evaluation (see in “The stage where usability evaluation takes place” in §28.3.1; Rettig, 1994). In geovisualization, researchers typically need to evaluate a concept or a prototype implementation. These prototypes can be used during system development for communicating with users. In order to evaluate interactivity (e.g., navigation through a virtual environment) and to obtain accurate performance measures — such as time taken by a user to complete a specific task, their success or error rates, evaluation with a functioning software prototype is required (Andrienko et al., 2002). An artifact under evaluation may be a full system (either as a prototype or a functioning system) or a component of it. Evaluation of a full system allows us to consider interaction between various components but effectiveness of each component may be easier to assess by evaluating them individually.

Approaches to usability evaluation

Usability evaluation can be undertaken using a number of approaches according to whether it is user, design/system expert, or theory based (Sweeney et al., 1993). A user-based evaluation involves users completing tasks in the environment whereas expert-based evaluation involves evaluators using the system in a more structured way in order to determine whether the system corresponds to predefined design criteria and some general human factor principles. These techniques commonly referred to as “usability inspection methods” (Nielsen and Mack, 1994), are not widely used for geovisualization at present. In a theory-based evaluation, a designer or evaluator can assess the match between user tasks that need to be supported and the system’s specification to generate quantitative values on learnability or usability.

The methods used also depend on the type of data that needs to be collected either to improve particular aspects of a system or for research purposes. There are usability evaluation methods to gather both qualitative and/or quantitative information and they are commonly combined in order to obtain complementary data. For instance, performance measurements are recorded and commonly analyzed using a statistical method to detect trends or usability problems with the system. These measurements, however, are often of greater value when accompanied by supplementary information from users about their perceptions of the usefulness of the system. Subjective data of this form is typically gathered using techniques such as interviews or questionnaires.

An example for an important assessment method is the "thinking aloud study". The method was developed in order to investigate which human cognitive processes occur during problem solving. The technique was transferred into HCI research where it is often applied. While working with a software tool, participants are asked to verbalize their thoughts as they try to solve a particular task. Participants usually do not only report how they solve a particular task but also include information about their perceptions and feelings, such as fear and anger (Weidle and Wagner, 1994). Additionally, participants often subjectively comment on the prototype, which supports the identification of flaws and errors in the user interface. Thinking aloud results in data describing cognitive processes of which the participant is aware. Other processes might not be identified using this technique, since not all mental processes can be verbalized directly (Kirwan and Ainsworth, 1992; van Someren et al., 1994).

Therefore, a clear understanding of the purpose and aim of an evaluation helps in determining the methods to be employed and the data to be collected. However, practical considerations, such as the cost in time or money of particular techniques, can also be influential when choosing specific methods and planning an evaluation. The broad range of techniques discussed in §28.2 and §28.3 are but a sample of what is available. Furthermore, these methods can be customized so that we can address particular research questions through a well planned evaluation.

28.4 Discussion: Do We Need a Geovisualization Theory?

Currently, most geovisualization is still arrived at through a design process, based on accumulated experience codified in procedures, written design rules and unwritten individual and group knowledge. However, more formal theory can contribute to design guidelines, and the long-term payoff is design that is more likely to be valid across different applications of geovisualization and across culturally different user groups. Theory development is a long-term process; it takes enormous effort to carry out human studies to answer small questions about some part of the user interface to information. Nevertheless it can be worth the effort because the results are potentially lasting.

Geovisualization theory can be divided into two broad categories: that which comes from other disciplines such as Perceptual Science, Cognitive Science, or applied disciplines such as Human-Computer Interaction. There is also theory developed specifically in the context of geovisualization.

Although theory may originate from some other disciplines, the role of geovisualization researchers will be to extend it in ways that are specific to geovisualization. A good example of this is the large body of work that has been carried out on pseudo-color sequences. This concerns the way in which information variables, such as temperature, population density and the like can be best expressed on a map using color. The theory of perception suggests that using a luminance scale will express a monotonic (continuously increasing) variable most successfully, although saturation (vividness) of color will also work. The theory also suggests that a representation of the physical spectrum (relying upon color hue) will not be perceived as monotonic. These predictions have been shown empirically to apply to the problem of pseudo coloring. The result is a body of theory and a set of design guidelines specifically tailored to the needs of geovisualization (Ware, 1988; Brewer, 1994).

A key area of cognitive theory concerns the way that people use external imagery as a support in decision making (Zhang, 1997). Instruments for geovisualization can be regarded (amongst other things) as being cognitive decision support tools. People can cognitively operate much more effectively with an external artefact, such a map, than with a purely mental image. For example, maps are often essential tools in planning. We can cognitively use the map for rapid "what if?" scenarios when planning travel, for example, "what if I were to take this route rather than that?". With geographic information systems behind the geovisualization, interactive maps can provide far more powerful cognitive support tools that take advantage of all sorts of sophisticated data manipulations.

Cognitive theory can provide insights on how to better design the interfaces used for geovisualization. For example, it is known that visual and verbal working memory have very limited capacity and this can be a major bottleneck to the process of ideation. Modeling this, along with the system characteristics can be useful in answering questions such as whether and when multiple views of data are likely to be useful, for example, (see Ware, this volume (Chapter 29)) and Roberts, this volume (Chapter 8). Ultimately we may hope to develop a kind of extended cognitive theory that encompasses both human cognitive systems and the external computer-based geovisualization system and the two-way flow of information between the two. Such a theory could ultimately help guide the early stages of system design.

The evaluation methodologies that are appropriate to theory development are generally more rigorous than those required for usability design. Most methods used in visual science, cognitive science, and social science are potentially applicable. This level of effort is justified because the goal is to generate theories that will endure, rather than the quality of a single system. Because of this, it behooves researchers to be as rigorous as possible and to try to take a long-term perspective. For example, a study of the utility of stereoscopic display (Kirschenbauer, this volume (Chapter 18)) should ideally be undertaken with a very high-resolution display because stereoscopic depth perception is capable of taking into account very small differences in images. Doing the study with a low-resolution display may lead to useful insights, but we can confidently predict that displays will be better in the future.

Geovisualization is in its beginnings in terms of the development of a body of established theory. As indicated, much of the theory upon which we currently draw may have origins in other disciplines, but it will have been extended and refined in ways that make it specific to geovisualization. The related disciplines of Scientific Visualization, Information Visualization, Human-Computer Interaction and Cartography certainly have plenty to offer (MacEachren, 1995; Dix et al., 1998; Card et al., 1999; Chen, 1999; Ware, 2000).

J. Dykes, A.M. MacEachren, M-J. Kraak (2005), Exploring Geovisualization, Pergamon, 732pp. 0-08-044531-4

References

Andrienko, N., Andrienko, G., Voss, H., Bernardo, F., Hipolito, J., and Kretchmer, U., (2002) "Testing the usability of interactive maps in CommonGIS", *Cartographic and Geographic Information Science*, 29(4), 325-342.

Bevan, N., and Curson, I., (1999) "Planning and implementing user-centered design", *CHI 1999, Adjunct Proceedings, Pittsburgh*, ACM Press, New York, NY, USA. Online: http://www.usability.serco.com/research/publications.htm

Beyer, H., and Holtzblatt, K., (1998) *Contextual Design – Defining Customer-Centered Systems*. San Francisco: Morgan Kaufmann Publishers, p. 472.

Brewer, C. A., (1994) "Color use guidelines for mapping and visualization", In: MacEachren, A. M., and Taylor, D. R. F., (eds.), Visualization in Modern Cartography, Vol. 2. Oxford: Elsevier Science Ltd., pp. 123-148.

Card, S. K., Mackinlay, J. D., and Shneiderman, B., (eds.), (1999) *Readings in Information Visualization: Using Vision to Think*. San Francisco: Morgan Kaufmann Publishers.

Carroll, J. M., (1997) "Scenario-based design", In: Helander, M., Landauer, T. K., and Prabhu, P., (eds.), *Handbook of Human–Computer Interaction*. Amsterdam, North Holland: Elsevier, pp. 383-406.

Carroll, J. M., (2000) *Making Use – Scenario-Based Design of Human–Computer Interactions*. Cambridge, MA: The MIT Press, p. 368.

Chen, C., (1999) *Information Visualization and Virtual Environments*. London: Springer-Verlag, p. 223.

Dix, A. J., Finlay, J. E., Abowd, G. D., and Beale, R., (1998) *Human–Computer Interaction*. Englewood Cliffs: Prentice Hall.

Erickson, T., (1995) "Notes on design practice: stories and prototypes as catalysts for communication", In: Carroll, J. M., (ed.), *Scenario-Based Design, Envisioning Work and Technology in System Development*, John Wiley & Sons, Inc., New York, NY, USA, pp. 37-58.

Fuhrmann, S., (2003) *Facilitating wayfinding in desktop geovirtual environments*. Muenster: Institut für Geoinformatik, Westfälische Wilhelms-Universität, p. 177.

Fuhrmann, S., Schmidt, B., Berlin, K., and Kuhn, W., (2001) "Anforderungen an 3D-interaktionen in geo-virtuellen visualisierungsumgebungen", *Kartographische Nachrichten*, 51(4), 191-195.

Gahegan, M., Harrower, M., Rhyne, T.-M., and Wachowicz, M., (2001) "The integration of geographic visualization with databases, data mining, knowledge construction and geocomputation", *Cartography and Geographic Information Science*, 28(1), 29-44.

Gould, J. D., and Lewis, C., (1987) "Designing for usability: key principles and what designers think", In: Baecker, R. M., and Buxton, W. A. S., (eds.), *Readings in Human–Computer Interaction: A Multidisciplinary Approach*. San Mateo, CA: Morgan Kaufmann Publishers, Inc., pp. 528-539.

Hackos, J. T., and Redish, J. C., (1998) *User and Task Analysis for Interface Design*. New York: Wiley, p. 488.

J. Dykes, A.M. MacEachren, M-J. Kraak (2005), Exploring Geovisualization, Pergamon, 732pp. 0-08-044531-4

Hassenzahl, M., (2001) "The effect of perceived hedonic quality on product appealingness", *International Journal of Human–Computer Interaction*, 13(4), 481-499.

Henry, P., (1998) *User-Centered Information Design for Improved Software Usability*. Boston: Artech House, p. 250.

International Standards Organsiation (1998) "ISO 9241-11Ergonomic requirments for office work with visual display terminals (VDT)s – Part 11", *Guidance on Usability*. Genéve: International Organization for Standardization, p. 22.

Kirwan, B., and Ainsworth, L. K., (eds.), (1992) *A Guide to Task Analysis*. London: Taylor & Francis, p. 417.

Kuutti, K., (1995) "Work process: scenarios as a preliminary vocabulary", In: Carroll, J. M., (ed.), *Scenario-Based Design: Envisioning Work and Technology in System Development*. New York: Wiley, pp. 19-36.

Landauer, T. K., (1995) *The Trouble with Computers – Usefulness, Usability, and Productivity*. Cambridge, MA: The MIT Press, p. 425.

Lewis, J. R., (2001) "Current issues in usability evaluation", *International Journal of Human–Computer Interaction*, 13(4), 343-349.

Lewis, C., and Rieman, J., (1994) *Task-centered user interface design. A practical instruction*. Boulder, CO: Computer Science Department, University of Colorado-Boulder, Online: ftp://ftp.cs.colorado.edu/pub/cs/distribs/clewis/HCI-Design-Book

Lindgaard, G., (1994) *Usability Testing and System Evaluation – A Guide for Designing Useful Computer Systems*. London: Chapman & Hall, p. 393.

MacEachren, A. M., (1995) *How Maps Work: Representation, Visualization, and Design*. New York: The Guildford Press, p. 513.

MacEachren, A. M., and Kraak, M. J., (1997) "Exploratory cartographic visualization: advancing the agenda", *Computers & Geosciences*, 23(4), 335-344.

Mark, D. M., and Gould, M., (1991) "Interacting with geographic information: a commentary", *Photogrammetric Engineering and Remote Sensing*, 57(11), 1427-1430.

Nielsen, J., (1993) *Usability Engineering*. Boston: AP Professional.

Nielsen, J., and Mack, R. L., (eds.), (1994) *Usability Inspection Methods*. New York: Wiley, p. 413.

Norman, D. A., (1998) *The Invisible Computer*. Cambridge, MA: MIT Press.

Rettig, M. (1994). Prototyping for tiny fingers. *Communications of the ACM*, 37(4), 21–27.

Rubin, J., (1994) *Handbook of Usability Testing: How to Plan, Design, and Conduct Effective Tests*. New York: Wiley, p. 330.

Shepherd, A., (1995) "Task analysis as a framework for examining HCI tasks", In: Monk, A. F., and Gilbert, N., (eds.), *Perspectives on HCI – Diverse Approaches*. London: Academic Press, pp. 145-174.

Sheridan, T. B., (1997) "Task analysis, task allocation and supervisory control", In: Helander, M., Landauer, T. K., and Prabhu, P., (eds.), *Handbook of Human–Computer Interaction*. Amsterdam: Elsevier, pp. 87-105.

Slocum, T. A., Blok, C., Jiang, B., Koussoulakou, A., Montello, D. R., Fuhrmann, S., and Hedley, N. R., (2001) "Cognitive and Usability Issues In Geovisualization", *Cartography and Geographic Information Science*, 28(1), 61-75.

Sweeney, M., Maguire, M., and Shackel, B., (1993) "Evaluating user–computer interaction: a framework", *International Journal of Man-Machine Studies*, 38(4), 689-711.

van Someren, M. W., Barnard, Y. F., and Sandberg, J. A. C., (1994) *The Think Aloud Method – A Practical Guide to Modelling Cognitive Processes*. London: Academic Press, p. 208.

Ware, C., (1988) "Color sequences for univariate maps: theory, experiments and principles", *IEEE Computer Graphics & Applications*, 8(5), 41-49.

Ware, C., (2000) *Information Visualization: Perception for Design*. San Francisco: Morgan Kaufmann Publishers, p. 384.

Weidle, R., and Wagner, A. C., (1994) "Die Methode des Lauten Denkens", In: Huber, G. L., and Mandl, H., (eds.), *Verbale Daten*. Weinheim: Beltz – Psychologie-Verl. Union, pp. 81-103.

Zhang, J., (1997) "The nature of external representations in problem solving", *Cognitive Science*, 21(2), 179-217.