beziehen müssen, um Planungsinhalte besser begreifbar zu machen. Die Umfrage zeigt, dass es eine sinnvolle Forschungsaufgabe sein wird, neue Möglichkeiten der computergrafischen Darstellung landschaftsplanerischer Belange auszuloten und zu erproben, um den defizitären Kommunikationsprozess der Landschaftsplanung spürbar zu verbessern. Darüber hinaus gilt es, Methoden zur Integration interaktiver 3D-Landschaftsvisualisierungen in den Planungsprozess zu entwickeln und mit der Praxis zu erproben (Herwig et al. 2000; Geier et al. 2001).

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Research Challenges in Geovisualization[1)]

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1 Introduction

The special issue of *Cartography and Geographic Information Science* presents the results of an international collaboration to delineate a four-part research agenda for geovisualization. Geovisualization integrates approaches from visualization in scientific computing (ViSC), cartography, image analysis, information visualization, exploratory data analysis (EDA), and geographic information systems (GISystems) to provide theory, methods, and tools for visual exploration, analysis, synthesis, and presentation of geospatial data (any data having geospatial referencing). Primary themes addressed here are representation of geospatial information, integration of visual with computational methods of knowledge construction, interface design for geovisualization environments, and cognitive/usability aspects of geovisualization. The International Cartographic Association (ICA) Commission on Visualization and Virtual Environments took the lead in developing this comprehensive research agenda by organizing an international team to address each theme. The teams included both commission members and others active in geovisualization and related areas. Participants represent a range of disciplines and include representatives from government and the private sector, as well as academic researchers. Each team was assisted by an expert from outside geographic information science who provided critical review of white papers prior to completion of final manuscripts. The full set of manuscripts was then submitted for formal peer review. On the Commission's web site www.geovista.psu.edu/icavis the research agenda development process is

1) *Summary of: Research Challenges in Geovisualization by Alan M. MacEachren and Menno-Jan Kraak, originally published in Cartography and Geographic Information Systems, 28(1), 3–12.*

detailed. The essay provides an overview of the organizational, technological, and scientific context for the research agenda setting effort, emphasizing changes in each that prompted the project at this time. Next, it outlines the core issues identified within each agenda theme and summarize challenges identified. Then, four crosscutting challenges are delineated. It concludes with recommendations for action. In this special issue of Kartographische Nachrichten the themes and issues are presented.

The research agenda focuses on four primary themes: representation, integration with knowledge construction and geocomputation interface design, and cognition – usability.

2 Representation

Representation is, in itself, a crosscutting theme. Dramatic changes in visual representation possibilities and the data to be represented, coupled with the fundamental questions that arise as we try to take advantage of them, provide the driving force behind this research agenda effort. With data, challenges for traditional representation methods are posed by very large, multivariate geospatial data sets that include both the third spatial dimension (e.g., volumetric atmospheric data) and time. New representational tools that help respond to these challenges include interactivity, animation, hyperlinking, immersive environments, and dynamic object behaviors. Maps have represented the world successfully for centuries by making the world understandable through systematic abstraction that retains the iconicity of space depicting space. Advances in methods and technologies are blurring the lines among maps and other forms of visual representation and pushing the bounds of "map" as a concept toward both a more realistic and a more abstract depiction. As a result there is a variety of unanswered questions about the attributes and implications of "maps".

The representation agenda team (led by David Fairbairn) focused on visual representation as it relates to five issues: semiotics and meaning (how visual depiction relates to underlying meaning); data (how visual depiction relates to interpretations and structures imposed on data); map use (how visual depiction relates to desired uses); map users (how visual depiction relates to human–computer interaction); and technology (how visual depiction can/should take advantage of technological advances). While the focus is on visual representation, underlying data representation issues as well as non-visual perceptible representation methods (using sound, haptics) are also addressed. The team delineated five challenge categories, with four to eight specific challenges detailed in each. The categories are summarized here as follows:

- To develop a theory for georepresentation and formalizing representation methods.
- To develop new forms of representation that support the understanding of geospatial phenomena and space–time processes.
- To adapt representation methods to meet the changing nature of data to be represented.
- Adapting representation methods to the increasing range in kinds of task that visual geospatial representations must support.
- To take advantage of recent (and anticipated) technological advances in both hardware and data formats.

3 Visualization – Computation Integration

While continued advance in geovisualization methods and tools is important, geospatial data volumes are so large and the interactions among variables so complex that human vision cannot be successful in isolation. Fundamental advances in our approach to (and success at) knowledge construction from geospatial data are most likely if we can integrate the advantages of computational and visual approaches. The goal of this integration is visually enabled knowledge construction tools that facilitate both the process of uncovering patterns and relationships in complex data and subsequent explanation of those patterns and relationships.

A focus here is on tools that can function in the absence of pre-determined hypotheses. Recent developments in three domains are relevant. First, is exploratory visual analysis, a multidisciplinary effort (that includes geovisualization) to develop visual approaches to data analysis. Second, knowledge discovery in databases (KDD) focuses on developing methods that find useful and valid structure in large volumes of data and providing some means of explaining it. Third,

geocomputation directs attention to developing methods to model and analyze a range of highly complex, often non-deterministic problems related to geospatial data. Specific issues addressed by the integration agenda team (led by Mark Gahegan) include: visual approaches to data mining, visual support for computational knowledge construction methods, and databases and data models necessary to make visually-led geospatial knowledge construction a reality. Challenges identified are grouped into the following categories, summarized as follows:

- To develop visual approaches to geospatial data mining, thus to using visual methods for uncovering unknown patterns and relationships in large geospatial data sets.
- To integrate visual and computational tools that enable human and machine to collaborate in the process of knowledge construction.
- To address the engineering problems of bringing together disparate technologies, each with established tools, systems, data structures and interfaces.

Additionally the following questions were raised:

- How to explicitly incorporate the location and time components of multivariate data within visual and analytical methods?
- How to represent geographic knowledge; specifically how to include the rich conceptual structures of this knowledge in computationally based models?
- How to incorporate geographic meaning within visualization environments?

4 Interfaces

For advances in visual representation and visually enabled knowledge construction to have the greatest impact, and to extend these methods beyond use by individual experts, complementary advances are required in geovisualization interface design. New interface paradigms are needed that support interaction with advanced forms of representation and analysis that take advantage of multimodal methods for access to and interaction with information; work on small mobile displays; support group work; and can be adapted to support individual differences.

This research agenda team (led by William Cartwright) identifies four central interface themes within which challenges exist. These are: interfaces and representation of geography, interaction (particularly navigation and manipulation), universal access, and practical implementation of interfaces using new technologies. Challenges related to these themes are grouped into six categories, summarized as follows:

- To develop the understanding and mechanisms for capitalizing on the potential of geovisualization to prompt creative thinking.
- To extend our understanding of metaphor for geovisualization and develop principles for selection of appropriate metaphors.
- To investigate both interfaces to support the concept of a Digital Earth and the concept of Digital Earth as an interface.
- To extend our understanding of interface design to take advantage of the potential of virtual environments.
- To develop and assess formalizations for specifying interface operations appropriate to geovisualization environments.
- To develop a comprehensive user-centered design approach to geovisualization usability.

5 Cognitive/Usability Issues

The approaches taken to the three themes outlined above each raise issues concerning use and users of geovisualization environments. Whether our focus is on representation, knowledge construction, or interfaces, two common questions can be posed:

Does the tool work? and how?

These questions, of course, have many dimensions. How will people react to fully immersive environments, can they deal with the information density offered, are the navigation tools provided effective, and what factors determine success or failure of geovisualization? Our current understanding is particularly limited in relation to individual and group differences related to experience, sex, age, culture, and sensory disabilities and to the use of visualization collaboratively. Answering these questions becomes more urgent since the "map" is being used increasingly as a metaphor in the design of non-geospatial visualization tools.

The fourth research agenda team (led by Terry Slocum) addresses these issues directly, with a dual focus on cognition and usability. A fundamental problem for geovisualization is to un-

derstand (and take advantage of) the mechanism by which the dynamic, external visual representations offered by geovisualization serve as prompts for the creation and use of mental representations. With usability, emphasis is on delineating the advantages and disadvantages of the increasing array of geovisualization methods and technologies, in a wide range of contexts for a wide range of users. A related issue is the current lack of established paradigms for conducting cognitive or usability with highly interactive visual environments, particularly when those environments are designed for application to ill structured problems (e.g., knowledge construction or decision support). Challenges identified are grouped into seven categories.

- To develop cognitive theory to support, and assess usability of, methods for geovisualization
- To develop cognitive theory to support, and assess usability of, methods for geovisualization utilizing advances in dynamic (animated and highly interactive) displays
- To develop an integrated understanding of metaphors and knowledge schemata in the context of geovisualization interface design
- To understand individual and group differences related to use and usability of geovisualization.
- To extend our perspective on cognitive and usability issues associated with geovisualization to contexts that involve group work.
- To determine the contexts within which geovisualization is successful.
- To develop methods and tools that will enable the kinds of cognitive and usability research called for.

6 Crosscutting Research Challenges

From the above four fundamental crosscutting issues, that are particularly challenging, that will require a coordinated multi-disciplinary approach, and that have implications well beyond geovisualization can be derived:

- To develop the understanding and integrated technologies that make it possible to take advantage of the potential offered by increasingly experiential representation technologies.
- To develop a new generation of geovisualization methods and tools that support group work.
- To develop a human-centered approach to geovisualization.

Recommendations for action and more detail can be found in the special issue of Cartography and Geographic Information Systems (volume 28, number 1, 2001).

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