Title

NCGIA Research Initiative 8 (Formalizing Cartographic Knowledge): Scientific Report for the Specialist Meeting (95-15)

Authors

Buttenfield, Barbara P.
Dibble, Catherine

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NCGIA Research Initiative 8
Formalizing Cartographic Knowledge

Scientific Report for the Specialist Meeting

24-27 October, 1993
Buffalo, New York

by

Barbara P. Buttenfield, Initiative Leader
Department of Geography
University of Colorado
Boulder, Colorado 80309

and

Catherine Dibble, Graduate Research Assistant
Department of Geography
University of California
Santa Barbara, California 93106

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Executive Summary

This report is a summary of the Specialist meeting for NCGIA Research Initiative 8 entitled "Formalizing Cartographic Knowledge". The Specialist Meeting was held in Buffalo New York, 24-27 October 1993 to discuss knowledge representation and formalization issues relating to automation of cartographic processes. The challenge to automate cartographic design and generalization stems from the fact that much of cartographic expertise is understood only intuitively. Intuitive knowledge is ill-structured, and therefore difficult to formalize. Non-formal principles are difficult to exchange verbally or procedurally. Incorporation of sound cartographic principles into existing GIS software will free users to focus on their systematic research, and ensure that the cartographic products derived from GIS processing are informative and visually logical. In addition to the improvement in quality, formalization of cartographic knowledge may reduce the need for manual intervention in some parts of the cartographic process, thus reducing costs.

Thirty-four researchers and representatives from the public sector, private sector, and academia came from North America, Europe, and the United Kingdom for three days to prioritize a research agenda with particular emphasis on international collaboration. Initially, the scope of the initiative focused upon topographic and similar maps which are standardized in data content, data quality, and symbology. This focus was broadened to include other types of maps (for example soils maps) which are often produced in a GIS environment but whose design is not often serialized or standardized.

The four research topics given high priority are to formalize the language of cartographic elements and to standardize definitions of GIS processing operations, to implement formalized mechanisms to evaluate mapping system design, to impose more rigorous structure on the process of eliciting cartographic knowledge, and to embed cartographic knowledge into spatial data models and spatial data processing models. The sense of meeting participants is that international collaboration will hasten solutions to problems which confront many national mapping agencies and mapping houses. Commitments were voiced to make every effort to encourage international exchange, including visits, joint research projects, and collaborative publication. The focus on international cooperation is manifest in concurrent NCGIA efforts, most notably with the European Science Foundation (ESF) GISDATA Programme, although no single NCGIA Research Initiative has catalyzed as high a level of interest in the European research community. It is expected that research activity in Europe may equal or exceed the level in North America, during the life of this Initiative.

The authors wish to thank all the Specialist Meeting participants for their energy and enthusiasm in helping to generate research priorities for this initiative. Steering Committee members gave generous amounts of time and thoughtful input. We also extend a hearty thanks to the graduate student assistants for their hard work and patience in recording the discussion and otherwise helping to make the meeting run smoothly. For preparations behind the scenes, we thank Pat Shyhalla and Dawn Becker.

The Specialist Meeting and this report are contributions to Research Initiative 8 "Formalizing Cartographic Knowledge" of the National Center for Geographic Information and Analysis. We acknowledge support from a grant by the National Science Foundation (SBR-88-10917). Additional funding from U.S. Geological Survey to support Dr. Buttenfield's sabbatical research on Initiative 8 topics is also acknowledged. The moral support, advice and encouragement of Dr Joel Morrison was important in structuring the meeting agenda, and in making sense of the volume of notes and materials stemming from Initiative Meeting discussions. Travel support for a number of participants to attend the meeting was provided by Insitut Geographique National (France), the Norwegian Institut of Technology, Jagellonian University (Poland), the Royal Institut of Technology (Sweden), and the U.S. Defense Mapping Agency, and Intergraph Corporation.

1 Description and Scope of the Initiative

The challenge to automate cartographic tasks such as scale change, choice of an appropriate map window or footprint, or map compilation is complicated by the fact that much of the knowledge that allows human cartographers to make or modify a map is ill-structured. The intuitive understanding of relationships between graphic marks and geographic meaning is difficult to articulate and therefore difficult to formalize. To computerize the map compilation process would save national mapping agencies incredible amounts of time and labor, and improve the consistency of their data products. Without mechanisms to formalize principles and guidelines that are well-understood but difficult to exchange verbally or procedurally, manual intervention in the cartographic process continues to drive costs up; and the quality of products is often impaired.

Initially, the scope of the initiative focused upon non-thematic maps, such as topographic maps, road maps, and navigation charts, which are the most standardized cartographic products in terms of data content, data quality, and graphic presentation. Early in the Specialist Meeting this focus was broadened to include other types of maps (for example soils maps) which are often produced in a GIS environment but whose design is not often serialized or standardized.

2 The Specialist Meeting

The Specialist meeting provided an opportunity to bring together representatives from academia, federal agencies, and industry to discuss these issues and to identify research goals that could be met given current technology and current understanding of knowledge representation.

2.1 Steering Committee

The initiative leader organized a Steering Committee to assist in organizing the meeting agenda, drafting the open call for participation, initiating discussions during the meeting, and providing some forms of follow-up afterwards. Individuals were invited to join the Steering Committee over a period of several months, beginning in Fall, 1992.

Members of the Steering Committee were selected for breadth of interest and expertise in the cartographic community, international diversity, and demonstrated leadership and prominence in the research community. It is felt this helped to attract many of the participants who might otherwise have overlooked the meeting solicitation.

Steering Committee members included:

Kate Beard, NCGIA-Maine, USA
Geoff Dutton, Harvard Design and Mapping, USA
Peter Fisher, University of Leicester, UK
Roberta Lenczowski, Defense Mapping Agency, USA
Robert McMaster, University of Minnesota, USA
David Mark, NCGIA-Buffalo, USA
Jean-Claude Muller, ITC, The Netherlands
Robert Weibel, University of Zurich, Switzerland

2.2 Setting the Meeting Objectives

In preparation for the meeting, the steering Committee crated and agreed upon a set of objectives to guide the content of the call for participation. The call solicited position papers presenting either a solution to knowledge formalization in one or more of these areas or a discussion of impediments to overcome in generating a solution:

- Operational issues for automated cartographic production
- Data abstraction for cartographic representation
- Data representation, data handling, and cartometric analysis based on incomplete and imprecise knowledge
- Existing and emerging methods for the formalization of knowledge
  - expert systems, AI, rule bases
  - adaptive systems, genetic systems
  - amplified intelligence
  - novel methods, e.g.. hypermedia-based interactive logging
- Impacts of standardized rules encasing
  - standardized algorithms
  - standardized graphical user interfaces
  - standardized symbology
- Institutional exchange to coordinate use and dissemination of technology and knowledge, with national and international implications
- Impacts of standard exchange formats, and of feature and attribute coding conventions
- Formalizations of human reasoning processes about spatial patterns and graphical display

2.3 Open Call Solicitation

The open call solicitation went out in April 1993 by electronic dissemination on GIS-L, INGRAFX, and other list servers. A copy of the solicitation appears in Appendix A. Handouts were distributed at about the same time at numerous cartographic and geographic conferences, including International Cartographic Association meetings in Cologne, Germany, the Association of American Geographers meeting in Atlanta, Georgia, and the Canadian Cartographic Association meetings in Vancouver, British Columbia. Mailings targeted specific individuals to submit papers. A second open call solicitation went out in late May.

Thirty papers were received by the 1 July target date. Following a peer review, twenty-one were provisionally accepted, with reviewer comments sent back to authors for revision. At least one Steering Committee member reviewed each abstract. Nineteen revised papers by twenty-one authors were resubmitted, and these authors formed the group of participants.

Paper titles are listed in Appendix D, and are not included in this volume due to space constraints. Many of the papers have been published in other outlets since the Specialist

Meeting. Interested readers are encouraged to contact participants directly.

2.2 Specialist Meeting Participants

Roughly twenty-five participants from twelve countries participated in the meeting. These people came from a diversity of disciplines representing academia, federal agencies, and industry. Four individuals did not submit papers, and attended the meeting to participate in discussions. The small meeting size was due in part to an attempt to keep the Specialist Meeting at an intimate size, and to encourage dialog among a group of scientists whose native languages varied widely.   Formal conference sessions were held in English, and informal discussions were pursued in English, French, and German, depending on who was involved.

A number of participants have been involved in previous initiative efforts. However, an effort was made to involve individuals with no previous association with NCGIA and outside the domain of geographic information systems. The participant list is included below. For complete address and affiliation information see Appendix C.

2.2.1 Academics

North America
Marc P. Armstrong, University of Iowa USA
Lynne Elliott, University of Waterloo, Canada
Robert B. McMaster, University of Minnesota USA
Michael Rheault, University de Sherbrooke, Canada

UK
Peter Fisher, Midlands Regional Research Lab UK
Christopher Jones, Cambridge University, UK

Europe
Jean-Georges Affholder, Institute Geographique National, France
Jochen Albrecht, Institute of Planning and Agronomy, Germany
Jan Terje Bjorke, Norwegian Institute of Technology, Norway
Wojtek Chelmicki, Jagiellonian University, Poland
Hans Hauska, Royal Institut of Technology, Sweden
Liqiu Meng, University Hannover, Germany
Jean-Claude Muller, Ruhr-Universitaet Bochum Germany
Tapani Sarjakoski, Finnish Geodetic Institut, Finland
Lars Schylberg, Royal Institut of Technology, Sweden
Robert Weibel, University of Zurich Switzerland

2.2.2   Private Sector

Geoff Dutton, Harvard Design and Mapping USA
Ignacio Guerrera, Intergraph Corporation USA

2.2.3 Public Sector

Jean-Georges Affholder, Institut Geographique National France
Roberta Linczowski, Defense Mapping Agency USA

2.2.4 NCGIA

Barbara Buttenfield, NCGIA - Buffalo (on sabbatical at US Geological Survey)
Michael Collins, NCGIA-Maine
William Mackaness, NCGIA - Maine
David Mark, NCGIA - Buffalo
Terry Smith, NCGIA-Santa Barbara

2.3 Meeting Format

The specialist meeting was held in Buffalo New York at the University Conference Inn for three and a half days from 24-27 October, 1993. The general format of the meeting along with other special activities are described in the following sections. A complete meeting agenda appears in Appendix B.

2.3.1 General Format

The general format of the meeting was a series of group discussions, alternating between small and large groups focusing on a single theme. Small groups were selected by the Steering Committee with the goal of mixing participants from different disciplines and affiliations. Small group membership changed throughout the meeting to insure the broadest possible interactions. Four themes were covered during the meeting.

For each theme, a series of questions were provided as a basis for discussion. The questions, developed by the Steering Committee, were intended to provoke discussion and to guide the potential scope of the session. In some cases the questions were refined or reworded by the group participants. Each group selected a spokesperson to report on the discussions that took place. After participants reconvened as a large group, spokespersons presented summaries of their small group discussions. Graduate student rapporteurs were assigned to each small group to record discussions and assist in compiling summaries.

2.3.2 Presentations and Software Demonstrations

On Monday afternoon, the participants visited the Geography Department Geographic Information and Analysis Laboratory (GIAL) to view demonstrations of GIS and mapping software, and to see presentations of a number of ongoing research projects.

2.3.3 Other Activities

On Sunday evening, a wine and cheese reception was held in the Geography Department on campus to introduce participants to departmental and NCGIA researchers and faculty.

On Tuesday afternoon, Professor Vince Ebert of the Geography Department led a walking tour of the Niagara Power Plant and Vista, Goat Island and the Niagara Falls. Dinner followed at the Riverside Inn in Lewiston.

3 Initiative Themes Covered in the Small Groups

The Specialist Meeting began with an introduction by Barbara Buttenfield. She distinguished various theoretical frameworks used to articulate knowledge about cartographic data production, cartographic design, and cartometric analysis. Three well-accepted frameworks are based loosely upon the concept that the cartographic process can be seen as a series of transformations. The transformational theme has been refined and expanded upon by Tobler in America, and by Gruenreich in Germany, among others. The American framework developed from the transformational view creates a digital representation whose components are associated with geographical meaning. One may approach this transformation linguistically, as do authors such as Nyerges, or by mathematical formalisms. Guptill's work takes yet another angle on the transformational metaphor, mapping "features as entities" onto "features as objects" and this influence runs through much of the U.S. Spatial Data Transfer Standard.

The German transformation is based upon modeling the landscape terrain, recording geographic features in a Digital Land Model and transforming its components to generate a symbolic representation, called a Digital Cartographic Model (Figure 1).   As the Americans distinguish between entities and objects, the Europeans distinguish items in the Land Model from their cartographic counterparts. In both cases, the elements in the cartographic representation are approximations of the geographic elements they represent.

Lots of discussion ensued. Given that the existing content or existing structure of the Knowledge transformation will dictate in large part the results of the transformation (regardless of the conceptual framework used to theorize about it), it becomes important to articulate exactly what kinds of knowledge are to be included in the knowledge transformation. One might easily adopt a particular taxonomy, such as Armstrong's (1991) triad of algorithmic (procedural) knowledge, geometric and topological (structural) knowledge, and geographic (semantic) knowledge. In an effort to break new ground at the Specialist Meeting, the group agreed to think carefully in the coming three days what types of knowledge are transformed.

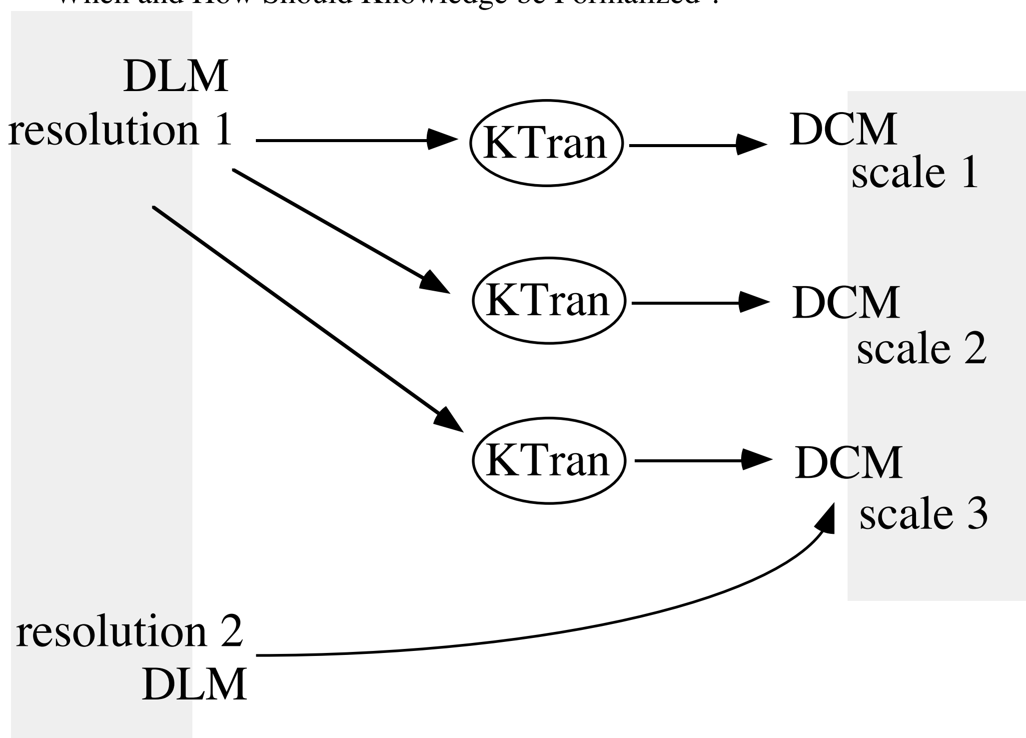
As to the question of how to prioritize the formalization of cartographic knowledge, the group addressed the question "With which data do we start?" for purposes of the Specialist Meeting discussions. As previously noted, the original intention of the Steering Committee was to focus on non-thematic data, and one suggestion was to draw upon the U.S. Mapping Science Committee's data foundation, as these layers are also contained in the set of FGDC framework data agreed upon by eleven spatial data producing agencies. The MSC data foundation is the "minimum directly observable or record able data from which other spatial data are referenced or compiled" (MSC, 1995). These foundation data are geodetic control, digital terrain, and digital ortho-imagery.

The sense of the group was that limiting the discussion to only three categories might constrain the group's ability to generate a robust research agenda. In addition to the foundation data, thematic data such as digital soils data would be considered.

From initial discussion, three sets of questions were agreed upon from the Steering Committee's set of four. The questions served as themes for small group discussions in the coming days. The questions were addressed in order.

Why Formalize Cartographic Knowledge?

What Methods Should be Applied?
When and How Should Knowledge be Formalized ?



DLM = Digital Land Model
KTran = Knowledge Transformation
DCM = Digital Cartographic Model

Figure 1. (redrawn from Gruenriech's work)
Digital Land Models (DLMs) (measurements of elevation or position) are generated at various levels of resolution. Each level is appropriate to create Digital Cartographic Models (DCMs) at multiple map scales. The Knowledge Transformation changes content of the resulting data or structure of the graphical representation.

3.1 Question 1: Why Formalize Cartographic Knowledge?

This question is related to the intensive effort (conceptual and computational) to anticipate all of the special cases that a set of formalized rules must accommodate. Specific graphical contexts can create dramatic differences in object placement, for example, which will affect name placement, feature displacement, selection of map symbol size, etc. etc. The small groups considered whether there are cartographic situations where obvious problems preclude application of formalized knowledge. It could be argued that what is not formalized must be dealt with by manual intervention, implying that formalization should be comprehensive. Partial formalization may leave problematic artifacts as a result of sequentially applied generalization operators. The groups discussed which design factors could be prioritized, and in what cartographic circumstances slippage of prioritizes might be tolerated.

Reasons warranting formalization that surfaced in small group discussions included standardization, that is, normalization will obtain uniform representations, as for compilation of map series over large or diverse geographic regions. Implementation of formalized knowledge could improve the efficiency of automated map production, and might improve communication of thematic map information. There are educational reasons for formalizing knowledge. Formalization should protect lay persons from graphical blunders, and render the mapping functions of many GIS packages easier to learn and use. In a completely formalized set-up (setting aside for the moment that this might be impossible), mapping defaults could be assured to avoid bias, and support data explanation and data exploration (i.e., understanding geographic process). By implication educational justifications extend support to policy and decision-making. Formalization of data and metadata acquisition was cited as a high priority for monitoring uncertainty, and tracking it through GIS operations. Finally, the identification of formal rules will help to define the extent of existing cartographic knowledge.

Once again in the full group, these ideas were restructured as follows. The reader should note there is an implied sequence. For example, improved system capabilities (implementing better graphic defaults, e.g.) should help to prevent bad mapping decisions (prevention) which in turn may lead to better understanding and explanation. The table below developed naturally, and the group subsequently realized an implicit prioritization what aspects should be tackled early on.

Why Formalize Cartographic Knowledge?

Efficiency (production and communication)
- to improve accuracy, consistency, efficiency, validity
- to generate standards while preserving flexibility

Implementation
- to build machines
- to improve mapping system capabilities

Data Acquisition
- to extract information (data and metadata)
- to acquire knowledge from the cartographic domain

Prevention
- protect users from poor mapping decisions

Understanding
- to identify rules
- to articulate map purpose
- to explore data without predefined paths or hypotheses

Explanation
- to link reality to data, in support of reasoning and inference
- to discover new theories, to push science forward

Education (direct quote from Geoff Dutton at the meeting)
"To help people access
explore
communicate

design
evaluate information about the world
and relevant to their concerns."

3.2 What Methods Should be Applied to Accomplish Knowledge Formalization?

Several questions are embedded in this topic, first the choice of a method, and second the determination that the method is both appropriate and robust. There was great variation in how the small groups dealt with this topic, and the full group summary and discussion was filled with fascination at the diversity.

One small group looked at data manipulation issues. Methods that have been applied in past research were quickly delineated, and discussion ranged around what types of data models would be appropriate for each approach.

Approach	What is Formalized
Artificial Intelligence	Data Fields
Amplified Intelligence	Data Layers
Expert Systems	Data Hierarchies
Neural Networks	Data Objects
Rule-Based Systems	Data Layers
Genetic Algorithms	Data Objects

The procedures by which each approach might be applied were seen to include extension of existing frameworks and mathematical models, formalization by logic or algebraic expression, rule production, algorithm design, and so forth. Adoption of industry, government, or international standards was seen as a starting point (building upon existing knowledge) as well as an ultimate objective (to validate an applied procedure).

The second small group reworded the question, returning with a very compact but also quite an elegant response. Their continuum defines degrees of formalization from de facto conventions through officially adopted standards. Knowledge formalization might be seen to traverse the continuum in a somewhat organic manner. Knowledge that works well will become more strongly embedded in the fabric of cartographic practice over time. The difference between a convention and a standard relates to three criteria: the first two are broader acceptance in a larger scope of mapping activities. Additional constraints will be discovered empirically as situations are encountered in which a formalized principle does not apply. As the boundaries of effective application become more clear, stricter adherence may be defined and (automatically) imposed.

What is Formalization?

Convention Standard

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Level of Acceptance
Scope of Acceptance
Degrees of Constraint

The third small group consolidated the first topic, taking the position that knowledge formalization can serve map production, map use, or human-machine communication. Formalization was seen as having as one objective to create a language to serve any one of the three. The group admitted that establishing a language will impose semiotic, semantic, and cultural implications. Description in any language will to some extent constrain the ways in which ideas are expressed (stress here is on the form of the expression, not on the content). Next, this group considered what types of knowledge the language should encompass:

declarative	(geometric and non-geometric facts)
procedural	(algorithms and methods)
structural	(geographical meaning including generating processes)
semantic	(meaning within a context)
episodic	(temporal connotations)

Applying the language metaphor to map production, map use and human computer interaction, the group determined that its vocabulary, syntax and grammar must be able to describe and analyze knowledge of map layout, color theory, and gestalt patterns (balance, symmetry, figure-ground, etc.) The language would be used to acquire knowledge about as well as manipulate single map elements, relations between map elements, and to describe and evaluate map composition as a whole. For human-computer interaction, the language should encompass knowledge about procedures as well as data items. The group discussed object-oriented programming languages as a step in this direction. Other language components relating to the human computer interaction included knowledge about passive and active navigational links, descriptive components for geographic modeling tasks, and language components to describe and reason with temporal pattern.

3.3 When Should Formalization Occur?

As the full group summaries were presented, it became difficult to separate discussion of appropriate methods from consideration of when in the cartographic process formalization should occur. The full group acknowledged that knowledge about machine representations of data is equally important to knowledge about map design, citing Brassel and Weibel's distinctions between statistical and cartographic processing. The group felt that knowledge formalization should proceed for all stages of data collection, organization, and manipulation; some felt that knowledge formalization could resolve issues of automatic metadata collection, and there was discussion about how to accomplish all of these tasks without impeding actual data analysis.

In a cartographic environment, formalized knowledge is context-dependent, as mentioned several times in this report. The biggest impediment to full automation is that information varies dynamically throughout the cartographic process. Generalization routines are commonly applied in a particular sequence. Terrain and hydrography are processed in sequence, since the river basins must logically contain the flow channels. Transportation is processed afterwards. As a consequence, the application of knowledge to the cartographic process is context-dependent. Each successive process will modify the graphic context, and may create unforeseen spatial conflicts or logical inconsistencies.

The point at which knowledge is acquired will impact upon the form (the structure) of its encoding. Knowledge about the geographic phenomenon (entities and processes) may be recorded by observation, description, or numeric measurement. Internal machine representations may be characterized in different form, focusing perhaps on the data model (items and relationships between items). Knowledge about processing procedures may take the form of parametric or algorithmic expression. And the graphical display may be formalized in principles of visual variables, visual contrast, and so forth.

The group considered encompassing metaphors for various structures, for example, can metaphors from Energy Physics be applied, to consider knowledge as particles or as flows? Is there an uncertainty principle for stored knowledge? How we think about knowledge and how we apply it will clearly affect how we structure it in computing environments. Continued discussion on meta-knowledge generated the following question: If the map object is not the same as the feature it represents, then is the knowledge associated with each component also different? This is not a rhetorical question. To utilize the acquired knowledge, it must be convertible or at least linkable to other formats and knowledge structures. Knowledge transformation forms an important area for research.

3.4 What are the Needs and Uses of Knowledge?

The group decided to apply the previous discussions to a specific problem, take the exercise of a specific application and determine what cartographic knowledge must be formalized to generate the GIS solution, at what stages, and in what forms. The process of self-observation proved most informative, as it pointed out areas where knowledge formalization would be most effective, most challenging, least informative, or impossible given current states of technology or of understanding.

The group chose a study completed by one of the participants, to maximize the possibility for accurate interpretations in the event of group questions. The selected case study focused on research by Bob McMaster (McMaster, R.B. 1988 "Modeling Community Vulnerability to Hazardous Materials using Geographic Information Systems". **Proceedings** Third International. Symposium on Spatial Data Handling, Sydney, Australia 17-19 August 1988: 143-156). The project had as its goal creation of a gridbased GIS to record and monitor a number of toxic waste sources in the Santa Monica urban area, including modeling capabilities to support an urban response in the event of a toxic waste accident. The article reports data collection, organization, GIS modeling, and creation of map displays of the models.

We xeroxed the article, sent the participants home with it in the afternoon, agreeing to read it and prepare for small group discussions in the morning. Small groups would focus on delivering map and data products to monitor Santa Monica toxic hazards, and on knowledge formalization that should facilitate generation and delivery. The full group identified four broad questions to address in small group discussions:

1. Identify the broad process by which the data/cartographic products will be derived. What are the stages? What types of knowledge are required at each stage?

2. What knowledge must be in the database to assist in deriving the product? Which of it is stage-specific? How is the knowledge to be transformed moving between

each successive stage?

3. What knowledge about the user is needed? What assumptions are made about the knowledge of the user?

4. What about knowledge requirements for data quality? How should the quality of knowledge be represented? (These two questions are inherently different.)

Three stages of knowledge formalization were identified in the subsequent discussion. Knowledge about the theoretical framework should support all aspects of data compilation, including abstraction and production. During the data production process, formalized knowledge should guide data compression and attribute categorization. Knowledge about metadata should direct data exchange and transfer. Generating map displays requires knowledge about the data, as derived above, plus graphical principles to avoid visual distortion that might bias decision support. Metadata knowledge differs from metadata in content, which emphasizes information not about the data but about the agencies who produce and exchange it. In the case of toxic hazards, the agency infrastructure would be both horizontal (public and private sector) as well as vertical (local, national and perhaps international government organizations, in the case of Santa Monica. The international component mentioned in discussions was a toxic air plume that might require notifying Mexican officials of an environmental hazard.) The groups talked briefly about transformations of knowledge between stages, but did not reach definitive conclusions in the short time allotted for discussion.

4 Research Agenda

The final discussion of the meeting revolved around the questions "What can be pursued in the next two years given the current state of technology and current state of knowledge?" AND "What do YOU want to pursue?". Throughout the previous days' discussions, participants had submitted a few priorities to the Initiative Leader on paper. During a full group session, each participant in turn mentioned one or more ideas, and these were also submitted in writing. All submitted materials as well as those recorded by rapporteurs during the discussion are reported here. Whenever possible, verbatim descriptions (as submitted) are included, and ascribed to specific individuals.

The reader should note that topics are listed as they were presented, in order around the table. Should show the reader that topics expressed by one person modified and refined subsequent discussion. We include the submitted topics verbatim, that is, in outline form or prose, precisely as submitted. The intention is to present the discussion as it developed. In the day following the Specialist Meeting, the Steering Committee members went through these topics, discussing, consolidating, and identifying four main categories to summarize what had transpired. The summarization (in outline form) follows this section. Participants who identified their name on submissions are acknowledged here. We do not acknowledge names if submissions did not include them.

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[1] ROB WEIBEL

One of the most serious impediments to a meaningful and flexible use of GIS is the lack of suitable techniques for the generalization of cartographic data. Such capabilities would reduce the cost of data capture, increase data consistency, and allow cross-database analysis. Under the supervision of Prof. R. Weibel, a group of Ph.D. and MS students is working on several aspects of the map generalization problem. The principal issues currently are the acquisition of generalization knowledge, the application of artificial intelligence techniques such as neural nets to generalization, and the development of components for an interactive generalization system with high-level interaction mechanisms.

1) Knowledge acquisition by comparison of map series
The study of generalization processes through the comparison of map series at different scales provides a possible alternative for knowledge acquisition in a "reverse engineering" approach. Based on the example of the generalization of forest parcels on the Swiss national map series, the feasibility of this method is evaluated and attempt is made to formalize knowledge about the generalization of forest parcels. Facts are to be identified with respect to the use of different generalization operators, and the conditions under which these actions take place. These facts should eventually be input to machine learning tools in order to formulate prototype rules.

2) Measures and procedures for the evaluation of the quality of generalization products
A critical link that is still missing from the generalization chain is the capability to evaluate the quality of products generated by different automated systems. The project involves the following tasks: review of available measures for generalization assessment; development of new methods, particularly with respect to topological consistency checking; development of non-quantitative, but standardized procedures for the comparison of automatically produced with manual results. For practical tests, the project makes use of a particular commercial generalization system. This work is carried out in collaboration with the OEEPE Working Group on Generalization. Co-advisor is Prof. E. Spiess, ETH Zurich.

3) Development of an interactive generalization editor based on a commercial GIS
Although most general-purpose commercial GIS include functions which can potentially be used for generalization, such as feature selection, line simplification procedures (e.g., Douglas-Peucker), line smoothing by splines, area dissolve and amalgamation, or reclassification, these capabilities cannot be optimally exploited by system users due to lack of appropriate interaction mechanisms and support facilities. This project therefore aims at extending a general-purpose GIS (ARC/INFO in this case) by additional software functions to build a pragmatic interactive generalization system. The key elements [2] include improved user interaction models, and the provision of support facilities (e.g., suggestion of generalization tolerances, highlighting of cluttered features). A secondary objective is to build a simple prototype to demo the concept of amplified intelligence.

4) Use of interaction logging and machine learning for knowledge acquisition
Interactive generalization systems do not only offer a possibility for productive work, but also offer the potential as tools for knowledge acquisition. It is intended to record the interactions of expert users with the generalization system (interaction logging) and later interpret these knowledge for knowledge acquisition. The interpretation of the resulting data (or facts) can be assisted by machine learning algorithms (implemented in a related project). This project aims at preparing the ground for the application of interactive systems to knowledge acquisition. This involves developing the conceptual basis and defining the requirements with respect to the elements of the knowledge acquisition chain: user interaction, generalization operators, interaction logging mechanisms and formats, machine learning techniques, and assessment of the result.

5) Use of neural nets for the generalization of linear and area features

Existing generalization methods are either based on algorithmic procedures or on knowledge-based techniques (e.g., expert systems). Neural nets (NN) hold the potential of a third alternative. NN are capable of learning from given sample situations, but their explanatory power is relatively low. Thus, while NN may not be the first option to support knowledge acquisition, we believe that their greatest potential is in replacing conventional algorithmic operators by a more holistic approach. The objective of the initial phase of this project is to evaluate the feasibility and performance of NN in comparison to conventional operators. Examples are taken from the domain of line simplification and smoothing, as well as area generalization by outline generalization and in raster mode.

6) Raster-based landuse generalization
-- Swiss Bureau of Statistics
-- specific

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(still from Weibel, in response to "What do YOU want to pursue?"

1) Analysis of requirements
    * map design and production
    * NMAs and private map production companies

2) Compile an inventory of guidelines in use at various NMAs
    * map design, compilation, and generalization
    * publish the inventory
    * make guidelines available on request (if possible)

3) Develop methods to assess the quality of a map product
    * related: compile a set of representative test databases

4) Develop methods for model transformation and generalization

5) Explore the potential of machine learning (ML) in knowledge formalization
    * interactive logging
    * analysis of facts databases from inventories and guidelines

6) Explore the potential of neural nets (NN)
    * cartographic knowledge "formalization"
    * substitutes of algorithmic methods.

7) Experiment with complex cartographic operators (name placement, displacement, generalization) using "novel" geometrical data structures.

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[2] BRANDON PLEWE

Cartographic Transfer Protocol

One of the basic needs of any system designed to distribute geographic information in real time over networks is the ability to quickly send and receive production-quality maps. The simple solution would be to put the map in some standard graphics format (i.e. PostScript, GIF) and send it as a file, to be decoded by the client software. All cartographic knowledge then would be contained explicitly in the file.

This could be problematic, however. There are several factors of this situation which must be considered:

1. Network transfer speed. The standard Internet rate of 56Kbps allows a 16 color 400x400 raster image to be transferred in about 5-6 seconds plus 1 for decoding and display), which is not bad for a semi-interactive system. However, if the maps are more complex (larger, more colors), or if they need to be truly interactive, this may be unacceptable. This may be solved by the very-high bandwidth networks of the future, but by then, the data to be transferred will certainly be more complex as well.

2. Variability of client software and hardware. When a document is distributed to millions of potential users, one has to take into account that they are on different systems, with varied capabilities (i.e. screen resolution, color depth, processing speed, font library). There is a large push in the electronic publishing arena to make e-texts platform independent--this is the primary reason for the SGML standard. If a raster map-image is sent (as is done now via the WWW) to a computer with poorer resolution or color abilities, it is often unusable by the reader. The SGML method is to have a semi-intelligent client, that can take the rudimentary style and context information, and interpret in into a form that is usable on that platform (i.e. match local fonts to standard style tags).

There are three approaches to a system like this:

1. Smart server/stupid client. This is basically the form of the first example. The server computer (or a human cartographer) build a graphic picture which happens to be a map, send that file entire to the client, which simply displays it. This has the advantage that the client doesn't need to even know it's a map, which means that it could be read by general electronic publishing (public domain) client software, that can interpret any graphic image as long as it is in a standard form, such as Mosaic and the WWW. I've already explained the disadvantages.
2. Smart server/smart client. This is the SGML approach. The server determines a graphic "style" for each element (maybe including a name/code and preferred symbology), sends a file to the client, which displays it, using the suggestions when possible, and finding a closest approximation when necessary.
3. Stupid server/smart client. This is basically a local GIS which is able to access remote spatial databases. This is the form that most SQL-based client/server applications are today. This is useful when a lot of analysis needs to be done on the information, but it is too large or too expensive to store locally. The data is never sent as a "map," but as individual geographic (not cartographic) elements when requested. The local software must completely decide how to make the maps. This gives the user the most (too much, in some cases) control over the map design, but would probably be almost impossible to do in the public domain.

It's funny (although understandable) that Mosaic/WWW/HTTP falls into category #2 with respect to text (or even #3, since it can be run sometimes without a server), but is certainly in category 1 with graphics. By the way, Gopher and WAIS seem to be #1, since the client only poses questions and displays results, with no interpretation by the client software.

I think approach #2 has not been touched for cartography (or for any graphic design). I would design a protocol for transferring maps (or possibly any graphic image) quickly, and in an intelligent, useful way:

1. There would certainly be some form of compression, built on graphic and cartographic

generalization principles, and other stuff.

2. There would be "style tags" that would be attached to elements. They could belong to a standard set (Hairline, Title, BodyText, DottedLine) which could be used for any graphic element. However, since geographic/cartographic information is so varied, there would have to be a way of defining styles on-the-fly. Thus, in the header file, it could say "Freeway should be a double black 2pt line, 2pt separation in RGB 128,255,128;" this definition would be taken literally if possible, or interpreted to the closest approximation possible on the client machine.
3. Even with compression, the files may be to large to transfer in real-time. A possible solution to this would be to sort the elements with some sort of priority, and display the elements as they arrive; user interaction (i.e. selecting an object) could be done at any time in the process. Perhaps the base map would be shown first, followed by thematic data. Or better yet, perhaps a rough, generalized map would appear very quickly, followed by detailed shape points as the client waits for the user to interact with the map (they could interact with the rough map immediately if possible, and not even bother loading the rest).
4. There would also be catching, so that frequently used themes and entities (i.e. reference base) would not have to be reloaded with every interaction.

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[3] BARBARA BUTTENFIELD

1. Implement extension of DLG-E data model to incorporate multiple appearances at multiple scales/resolutions as knowledge embedded in the header. Try it out with specific generalization/symbol operators.

2. Implement hypermedia system using this new data model with interactive logging capabilities to elicit knowledge from users in various mapping domains (NMA's, etc.)

3. Work with Marc Armstrong to specify rudimentary knowledge required for a graduated symbol thematic map.

4. Pursue international collaboration with an inventory project to determine what knowledge can and cannot be formalized by reverse engineering.

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[4] PETE FISHER

1. Generalization

i) Soil Maps scale change
1:16,000 --> 1:100,000
Is a MANY TO MANY relationship in attribute space.
We have explored this using search as well as rule-based strategies.
I will review the work -- possibly do more but plan to publication.

ii) Land Use -- Land Cover generalization

I am involved with work at Ispra, Italy, the EC research center EURATOM on generalization from Landsat TM-type data --> for the land cover layer. Again it is MANY --> MANY transformation.

2. I would like to pursue some of the cultural vs. Domain aspects of Knowledge, documenting some specific examples -- not necessarily coming up with a Knowledge base.

3. I plan to revise a program which currently does simulated choropleth symbolization to make an interactive KA tool for choropleth symbolization.

4. I want to do <u>something</u> on Evaluation.

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[5] JAN T. BJORKE

1. Study how to compute the useful information of a map, in the terms of information theory, at the TECHNICAL LEVEL.
   a. How to model spatial correlation in a way suitable for including in information theory.
   b. Apply the theory to some map-examples.

Evaluate and develop measurements of the efficiency of Cartographic Communication.
a) Develop the mathematical basis of this measure.
b) Calibration of the model to the perceptual characteristics of the human system.

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[6] [MICHAEL LEITNER]

1. Prototype rules derived from the inventory of the Austrian Map Series.
   -> Code them in Prolog or Lisp and feed them into some kind of an expert system

2. Apply other methods of knowledge acquisition than inventory of topographic map series, such as the interview approach or the analysis of specification manuals.
   -> Do that only for the Austrian cartographic/products
   -> Find out, which rules can be acquired from which method and make a quality comparison of each method.

====================================

[7]

1. to find prototypes of map products (before and after manual generalization)

2. to encode some specific aspects of these products

3. to develop an interactive computer system which produces similar output to those prototypes. All of the procedures, functions, parameters and their sequences will be stored.

==

[8] HANS HAUSKA

Short term
  Attempt to extract simple rules from NLS production manuals (subject to availability of interested workers available)
  Study possible parallelization of simplification.

Medium Term (subject to availability of research grants)
  * Initiate study on applicability of visual languages to of thematic maps.
  * Intelligent user interface for GIS

Long Term (funding needed)
  Combine study of generalization procedures. Rules etc.
  Cartographic Language
    -- Study map spec's and actual maps as vehicle to formalization of knowledge.
    -- Continued study of generalization in the raster domain.
    -- Study possibilities of using parallel computers

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[9] ANN DEAKIN

An investigation of "Policy Capture and the Delphi Method as techniques for modeling cartographic experts'/users' judgments/ratings of cartographic products. Could also be used to create the products themselves.

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[10] LARS SCHYLBERG

-- Raster based generalization operators

-- Displacement in cartographic generalization

-- Knowledge representation with close connections to usage in cartographic generalization operations.

-- Displacement in cartography
How to capture knowledge and how to represent these fact. Specifically when many different object classes are involved simultaneously.

-- Representation of cartographic knowledge, so it will be an integrated part of cartographic systems (usable for generalization operators and/or overall strategy).

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[11] WILLIAM MACKANESS

1. Identification of knowledge used in the synergy and combination of generalization operators.

2. Development of a set of evaluation criteria for assessment of graphics.

3. Optimization of interaction in design using task analysis.

4. Abstraction of cartographic information from remotely sensed imagery.

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[12] CHRIS JONES (* personal interests for research)

Cartographic Knowledge representation using deductive databases, in particular: classification systems; placenames.

Implementing generalization: high level control; lower level operators; appropriate data structures.

Hypermaps: implementation of experimental systems for public information, education, planning.

1. Map design rules for effective communication
Collate/synthesize information from textbooks, research papers and manuals in map production organization interviews with cartographers.
Fill in gaps in knowledge with experiments to test users on information received from map symbols and design.

2.* Rules for map generalization
i) Rules used in manual cartography -- from manuals, textbooks, interviews
ii) Implementation and experimentation with software for
a) high level control of generalization operators
b) individual object implementation

3.* Hypermaps
a) learn from existing research in hypermedia and human-computer interaction
b) implement experimental hypermap systems

4. Cartographic language
Design a map specification language that generates effective symbols for given sets of map objects.

5.* Encode knowledge of geographic classifications and geographic placenames

==

[13] DAVID MARK

1. How do topological theories of spatial relations constrain generalization, aggregation and displacement? That is, if the spatial relations are changed by the process, which (if any) such changes are acceptable and which are not?

2. I plan to start thinking about what aspects of geographic knowledge would be needed in a knowledge-based mapping system, and which are not, and hope to come up with some general principles.

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[14] MARC ARMSTRONG

1. Trying to understand the formalization of knowledge required to produce a stupid map.

2. Dealing with the computational complexity issues associated with the application of formalized knowledge in a map production context, including macro-tasks associated with map layout, micro-tasks associated
with generalization and their possible interactions.

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[15] MICHEL RHEAULT

Knowledge based system trying to incorporate "Graphicacy" applied to cartography in a thematic map context.

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[16] FEIBING ZHAN

-- Knowledge-based visualization of spatial information
   * Temporal and 3D
   * Traditional map making

-- Different Aspects of Conflict Resolution in Map Generalization
   * Knowledge Acquisition
   * Cognitive Aspects
   * Knowledge Representation
   * Machine Learning [sic Learning]

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[17] BOB MCMASTER

A) Evaluation of acquisition techniques for cartographic knowledge.

B) User interface design for procedural knowledge acquisition.

Knowledge Acquisition Methods
      Parallel approaches
      User-Interface Design

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[18] JEAN-CLAUDE MULLER

1) Monte Carlo simulation of map creation through random usage of 1 million rules and evaluation of the map realizations.

2) Development of appropriate interfaces for knowledge acquisition.

3) Modular solutions for automated generalization.

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[19] MICHAEL COLLINS

* representation of remotely sensed data in a GIS
* generalization of geographic information from this representation

1) Cartographic objects are rep'ns of real phenomena. These phenomena must be measured/observed in order to create a geographic rep'n. This measurement process involves *uncertainty*. GIS must represent uncertainty in both pos'n (x,y,z) and attribute. These uncertainties will be useful in generalization and cartographic rep'n.

2) Geographic information should be stored in a "natural" (geodetic) coordinate system, i.e. ellipsoidal coordinates and height (above the geoid). In this way the information can be shared on a global scale. Especially important for "raster data" such as base maps, photogrammetric data, remote sensing data.

Thoughts on Procedure

1) Summarize research agenda and record dissenting voices and controversial topics (a group effort). Publish this abbreviated record of this workshop in a journal article co-authored by those who work on it (whether they are on the steering committee or not). The document becomes a published "preface" to the I-8 research.

2) Let research efforts run for a mutually agreeable time and then coordinate the publication of research *resulting from* I8 in a single unit (book, special issue). This keeps all participants "in the loop" for the whole life cycle of I-8. Papers ready to publish now are not really resulting from I-8 brainstorming.

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[20] JEAN-GEORGES AFFHOLDER

Generalization operators: conflicts and interactions

Knowledge acquisition and elicitation: new methods to elicit knowledge

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[21] LIQIU MENG

1) I think we should pay more attention to the structuring of data and knowledge. In many existing cartographic systems, we do have enough knowledge (primitive knowledge pieces which are formalized by means of functions, procedures, rules, frames ...). What we still miss is a mechanism which can control the usage of knowledge (dynamic metaknowledge).

2) It may be useful to apply neural nets in some subprocesses of generalization. e.g. those which are context dependent.

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[22] IGNACIO GUERRERO

1. Algorithm / operator design
    -- standardize definition/terminology
    -- Emphasis on algorithms for point and area features
    -- Displacement

2. Measures
    -- define set of measures for generalization

3. Data structures to enable efficient cartographic update. Object knowledge encoding.

=====================================

[23] LYNNE ELLIOTT

1. Cartographic language -- standard names for operators

2. Develop guidance as to what formalization method would be best to formalize what kind of knowledge.

3. Apply conceptual idea to the actual generalization of mapping agency spatial data.

4. Develop user interfaces to aid uneducated users in creating acceptable maps.

5. Determine the threshold of how much info needs to be included by data producers to ensure appropriate applications are performed.

1. Continue working with the Ontario Provincial Mapping agency to establish guidelines for the generalization of a large-scale database to produce small-scale maps and digital data products. Interested particularly in model generalization because it seems more possible to achieve successful results. The Ontario government and ESRI Canada are very interested in continuing this research.

2. Investigate a method of standardizing terms that are used to describe generalization operators.

3. Contact Canadian mapping agencies like the Canada Centre for Mapping and the Canadian Hydrographic Service and determine their needs and to possibly continue current research with them. Interested in investigating their guidelines for map and data base production.

===

[24] TAPANI SARJAKOSKI

-- language issue for cartography
   * data (=map) description language
   * data (=map) manipulation language

-- user
  * modeling of users knowledge
  * modeling of the message passing   user <----> machine

actually all of these are part of modeling the cartographic communication process.

1) User modeling, cartographic communication, man-machine communication
  focus: theoretical model for man-machine communication, including user modeling

2) Model generalization and multiple representations related to topographical data.

3) Encoding of quality information in GIS-databases and propagation of errors.

4) Study of the quality of Corine-Landcover data in Finland (European Community project)

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[25 ANDRE SKUPIN

In the context of generalization, investigate manuals of National Mapping Agencies.

*** Deeper Evaluation of Toepfer's work: ***

WHY? -- during the conference I found major misconceptions about practical and theoretical issues of the radical law. The radical law seems to be seen as a rather mechanistic tool. Further developments and resulting methodologies are widely unknown in the English-speaking world.

==

[26] FINAL EXAM CARTOGRAPHY 1 1/2 hrs. (Answer all questions)

1. What should be the balance between declarative knowledge (information stored in the database) and procedural knowledge (knowledge in the engine)?

2. Develop a set of evaluation criteria that enable the assessment of digital maps created through knowledge based systems.

3. Formalization of cartographic knowledge is mute without tangible graphical output. Therefore develop a set of generalization operators that are able to execute the "wishes" of a cartographic expert system (CES).

4. Itemize the knowledge used in the selection and operation of those generalization operators identified in the previous question.

4a. And knowledge of interplay between generalization operators

5. Purpose is dictated by user and usage; develop a set of questions that enable the system to identify use and user in a taxonomy of purpose.

6. The role of the user is guaranteed in GIS and EDA environments. Some decisions will remain the prerogative of the user while other decisions will be made by the system. Identify and determine the best opportunity of these decisions.

7. "Future developments in GIS and EDA techniques will make much research in formalization of cartographic knowledge redundant." Discuss.

==

[27] BOBBI LENCZOWSKI

Work on the cartographic data dictionary -- toward standardization of definitions of the elements.

Analysis of the restrictions and flexibility of standards development as part of the formalization process.

Techniques to simplify user tools to do cartographic visualization when delivered data set is "center-line." (Does a data set need to implicitly contain displacement information.)

Dataset generalization -- i.e. the integrated elements NOT JUST LINES; NOT JUST NAMES.

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I. Define "cartographic knowledge" to help bound problem

II. Enumerate types and sources of Cartographic Knowledge

III. How is Cartographic Knowledge transferred (characterize the senders, receivers, channels)

IV. Describe how Cartographic Knowledge is encapsulated/stored in mapping systems.

V. Relate storage methods to general AI approaches (Expert systems, Semantic and neural nets, OOP and OODB, Relational DB, Frames, Genetic Programming)

VI. Identify promising representations for Cartographic Knowledge with respect to Carto techniques, User Interaction, Map Design, Knowledge acquisition, Map types and purposes

VII. Proof-of-concept exercise:

Encode knowledge that would enable users to plot maps of a given graphic on a wide range of devices, such as Pen Plotter, Electrostatic Plotters, Laser Printers, Facsimile, NTSC video, etc. adjusting scale, content, symbolism, color, shading, line weights, text size and font, etc. to optimize the visual channel being used.

(much non-Cartographic Knowledge will also be required, but it can be acquired and instantiated in the same way as Cartographic Knowledge, hopefully)

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[28] [???]

Research Areas for Formalization:

Effective process to gather needs from user so that delivered product can be appropriately fashioned by the "cartographer."

Descriptions of knowledge *representations* so that the accumulation of data, which constitutes the basic elements of a particular body of knowledge, can be subjected to various "transformations" which result in information.

Definitions:

e.g. zip code data: single instances of facts with meaning

e.g. zip codes used by a delivery service
information: outcome of operation of rules/formulas, etc. on several pieces of data which removes uncertainty in a decision-making activity

Descriptions of "transformations" with recommendations for appropriate use of languages and operators and databases for particular cartographic applications.

==

[29] Geoffrey Dutton

1) Develop novel data representations capable of incorporating "knowledge" in spatial data. My QTM model and associated bit-strings are my starting point. (However, the bit string need not represent the QTM model only, as any hierarchy can be encoded in such a manner.)

2) Explore the capacity of genetic classifiers and programming to manipulate such data directly, using the data portion and the knowledge portion of the strings to negotiate spatial competition when rendering maps from such data.

I welcome collaborators who can extend or improve on this basic approach.

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[30] JOCHEN ALBRECHT

* visual *interactive* query

* visual interaction on-screen that triggers GIS functions

* maps not as final product but manipulation tools to be used in real time

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[31] CATHERINE DIBBLE

(1) Exploring fundamental spatial structures and abstract representations of structures (Geoff Dutton's "computational spaces") that will help us represent and model more unified and more general types of spatial interactions than is currently captured by the *discrete* state of that art.

(2) Exploring evolutionary computation and Holland classifier systems for the adaptive, *reportable*, machine-driven elicitation and evolution of several classes of cartographic knowledge, generalization, etc. INCLUDING *AESTHETICS* AND CULTURAL OR INDIVIDUAL STYLES OR PREFERENCES. Adaptive rule bases, some general and some specific to map purposes. Per Dibble "The Cartographer's Apprentice" April 1993

6 Summary of Research Priorities

Immediately following the meeting, Steering Committee members assembled all the research topic write-ups. Contributing their own notes from the final session, they collated four categories of topics. This collective outline was presented by five Steering Committee members (the four whose names appear below in parentheses, and the Initiative Leader) three days afterwards, at the Minneapolis GIS/LIS '93 convention. The presentations constituted a panel session at the conference. There was a large audience (95 people were counted) and the presentations generated a good deal of discussion at the meetings. Steering Committee members felt this was an effective way to disseminate results of Specialist Meeting discussions quickly.

The outline of topics is included here. Names in parentheses indicate the Steering Committee member who presented the topic. Topics are purposefully not expanded into prose, to show the precise topical summary of research priorities, and to show the outline which generated such good discussion at Minneapolis.

Research Priorities on Formalizing Cartographic Knowledge
Revised Call for Participation in an International Agenda

Category 1 - Formalizing a Cartographic Language (Pete Fisher)

What to Accomplish:
- standardizing definitions of terms / elements / GIS commands
- standardizing labels for knowledge transformations
- descriptions of knowledge representations for map description and manipulation

Research Priorities:
1. Visual Language Formalization TOP-DOWN
   creating a formal cartographic language for design and modeling
2. Knowledge Engineering and Reverse Engineering of maps and textbooks
   incorporating knowledge from various mapping cultures and
   incorporating domain knowledge from experts
3. Atomistic/Molecular Approach BOTTOM UP

Breaking out the smallest units of a mapping problem
Strive for as may pieces as possible

4. Of overarching importance: How do we quantify evaluation to measure success?
   Any aspect of evaluation
   Use multi-objective goal programming to assist sorting alternatives

Category 2 - Formalizing Evaluation of Design (Rob Weibel)

Research Priorities:
- Develop measures of efficiency / accuracy / user satisfaction
- Modeling effectiveness of communication (utility)
- Adopt emerging visualization tools to assist - hypermedia, interactive logging
- Adopt qualitative as well as quantitative methods - semi-structured interviewing
- Return to the early empirical paradigms mostly discarded by cartographers
  - but refine the old psychophysical approach to accommodate cognition, e.g.

Category 3 - Knowledge Acquisition and Elicitation (Bobbi Linczowski)

Questions to be Answered:
- are methods suited to specific knowledge types?
- how can we model users knowledge?
- how can we embed knowledge into user interfaces?
- how can we apply new methods to elicit knowledge?
  - machine learning
  - amplified intelligence
  - transaction log records

Examples of Research Projects:
- Reverse Engineering of NMA series
- Inventory of guidelines and production standards currently in use
  - analysis of standards (constraint vs. flexibility)
  - analysis of anticipated user requirements

Generic Priorities:
- cultural and domain knowledge of practitioners must be utilized
- international comparisons

Category 4 - Structuring / Modeling Knowledge (Geoff Dutton)

Research Priorities
- Embedding knowledge in data models
  - promising representations for knowledge
  - applying complex operators to novel data structures
- Mechanisms to guide use of knowledge
  - metaknowledge and dynamic metaknowledge
  - data structures w/ knowledge for efficient update
- Generalization Operators
  - conflict detection and resolution (interactions between conflict resolution tools)
  - rule generation and testing
  - intelligent device drivers
  - complex operators and novel data structures

7 Meeting Summary

The Specialist Meeting was held in Buffalo New York, 24-27 October 1993 to discuss knowledge representation and formalization issues relating to automation of cartographic processes. The challenge to automate cartographic design and generalization stems from the fact that much of cartographic expertise is understood only intuitively. Intuitive knowledge is ill-structured, and therefore difficult to formalize. Non-formal principles are difficult to exchange verbally or procedurally. Incorporation of sound cartographic principles into existing GIS software will free users to focus on their systematic research, and ensure that the cartographic products derived from GIS processing are informative and visually logical. In addition to the improvement in quality, formalization of cartographic knowledge may reduce the need for manual intervention in some parts of the cartographic process, thus reducing costs.

Thirty-four researchers and representatives from the public sector, private sector, and academia came from North America, Europe, and the United Kingdom for three days to prioritize a research agenda with particular emphasis on international collaboration. Initially, the scope of the initiative focused upon topographic and similar maps which are standardized in data content, data quality, and symbology. This focus was broadened to include other types of maps (for example soils maps) which are often produced in a GIS environment but whose design is not often serialized or standardized.

The four research topics given high priority are to formalize the language of cartographic elements and to standardize definitions of GIS processing operations, to implement formalized mechanisms to evaluate mapping system design, to impose more rigorous structure on the process of eliciting cartographic knowledge, and to embed cartographic knowledge into spatial data models and spatial data processing models. The sense of meeting participants is that international collaboration will hasten solutions to problems which confront many national mapping agencies and mapping houses. Commitments were voiced to make every effort to encourage international exchange, including visits, joint research projects, and collaborative publication.

Appendix A: Call for Participation

30 April, 1993
Call for Papers / Call for Participation

Formalizing Cartographic Knowledge
Buffalo, New York, 24-27 October, 1993

Specialist Meeting of the NCGIA Research Initiative 8

The National Center for Geographic Information and Analysis (NCGIA) will hold a Specialist Meeting for Initiative 8 "Formalizing Cartographic Knowledge" at the SUNY-Buffalo University Conference Center, 24-27 October, 1993. The goal of the Specialist Meeting is to identify and prioritize research needs in automated map compilation, generalization and production, and to specify an appropriate agenda for undertaking the research over the next two years. The structure of the meeting will alternate small-group and full-group discussions about specific questions. Participants will have the exciting opportunity to make active contributions to this process. Support for lodging and travel to and from the meeting may be available to participants selected to attend.

The Specialist Meeting will bring together about 30 researchers concerned with formalizing rules and formalizing cartographic expertise in the context of automated mapping and GIS. We want to attract researchers from as broad an audience as possible. Areas of particular interest include but are not limited to Cartography, Geography, Engineering, Computer Science (primarily Database Design and Management, Knowledge Representation, and Computer Graphics and Vision), Psychology, and Cognitive Science. The Initiative Steering Committee will select participants for the Specialist Meeting based on the submission of working papers. Additional participants may be invited to address topics not adequately covered by the papers selected from among submitted papers.

Topics of Interest

Submissions of papers presenting original research, surveys, or position statements on all aspects of "Formalizing Cartographic Knowledge" are invited. Particular emphasis should be put on a broad area or specific problem domain where knowledge representation or formalizing rules and criteria will improve the efficiency, accuracy, or consistency of digital cartographic data, cartographic representation or cartometric analysis. Issues of cartographic data exchange and data compression may also be relevant. Topics of special relevance include:

- Operational issues for automated production of cartographic and geographic information
- Institutional exchange to coordinate use and dissemination of technology and knowledge, with national and international implications
- Data abstraction for cartographic representation
- Formalizations of human reasoning processes about spatial patterns and graphical display
- Data representation, data handling, and cartometric analysis based on incomplete and imprecise knowledge.
- Current state of the art for the formalization of knowledge in the context of expert systems, adaptive systems or genetic systems

- Impacts of standardized rules encasing standardized algorithms, standardized graphical user interfaces, standardized symbology.
- Impacts of standard exchange formats, and feature and attribute coding conventions.

Paper Submissions

Please submit 5 copies of a working paper of at least 2,000 words (8 double-spaced pages) and no more than 2,500 words to the Specialist Meeting coordinators by July 1, 1993. The purpose of the working paper is to pose and prioritize research problems that could or should be addressed in the coming two years, given the current state of technology and state of knowledge. The working paper must provide sufficient detail to allow the Steering Committee to assess the contribution. It must include appropriate references to the pertinent literature and previous work. Authors should append a biographical sketch (1/2 page). All manuscripts will be reviewed by at least three members of the Steering Committee, and one external reviewer. Authors of accepted papers will be expected to revise their paper based on reviewers' comments, and to submit the revision prior to the Specialist Meeting. Copies of the papers will be distributed to participants prior to the Meeting. An edited volume of the revised papers is planned to be published after the Specialist Meeting.

The role of NCGIA in this (and all) Specialist Meetings is to act as a catalyst for the national and international research community, and to foster an environment where ideas for research may be shared and disseminated. Participants will be encouraged to address their stated research issues in coming months, and opportunities to report on research progress at conference sessions and in the literature will be discussed at the Specialist Meeting. Collaborative efforts will be encouraged.

Important Dates:

Deadline for submissions of working papers:	July 1, 1993
Notification of acceptance:	August 10, 1993
Revised papers due:	Sept ember 10, 1993
Specialist meeting:	October 24-27, 1993

Specialist Meeting Coordinators:

Barbara P. Buttenfield (Initiative Leader)
Catherine Dibble (Senior Rapporteur)

National Center for Geographic Information and Analysis
301 Wilkeson, SUNY-Buffalo, Buffalo, New York 14261
e-mail: babs@geog.buffalo.edu
tel.: (716) 645-3834 or 645-2545
FAX: (716) 645-2329

Initiative Steering Committee:

Kate Beard, NCGIA-Maine, USA
Geoff Dutton, Harvard Design and Mapping, USA
Peter Fisher, University of Leicester, UK
Roberta Linczowski, Defense Mapping Agency, USA
Robert McMaster, University of Minnesota, USA
David Mark, NCGIA-Buffalo, USA
Jean-Claude Muller, ITC, The Netherlands
Robert Weibel, University of Zurich, Switzerland

Participants and Visitors

Jean-Georges Affholder
Institut Geographique National
IGN/DT/SR/COGIT
BP 68-2, Avenue Pasteur
94 160 Saint Mande, France
AFFHOLDER@COGIT.IGN.FR

Jochen Albrecht (Visitor)
Institut of Planning and Agronomy
Postfach 1553
1848 Vechta, Germany
JALBRECTH@DOSUNI1

Marc P. Armstrong
Department of Geography
University of Iowa
Iowa City, Iowa 52242
ARMSTRNG@
UMAXC.WEEG.UIOWA.EDU

Jan Terje Bjorke
Department of Surveying and Mapping
The Norwegian Institut of Technology
University of Trondheim
N-7034 Trondheim, Norway
BJORKE@IGF.UNIT.NO

Wojtek Chelmicki (Visitor)
Institut of Geography
Jagiellonian University
ul.Grodska 64
31-044 Krakow, Poland
UGCHELMICK@CYF-KR.PL.EDU

Michael Collins
NCGIA/Dept. Surveying Engineering
University of Maine
Orono ME 04469
COLLINS@
GROUSE.UMESVE.MAINE.EDU

Lynne Elliot
Mapping, Analysis, and Design
Faculty of Environmental Studies
University of Waterloo
Waterloo, ONtario N2L 3G1 Canada
LELLIOT@WATSERV.UWATERLOO.CA

Dietmar Gruenreich
Institut fur Kartographie
University Hannover
Appelstrasse 9A
30167 Hannover 1, Germany

Ignacio Guerrero
Mapping Sciences Division
Intergraph Corporation
Huntsville, Alabama 35894-0001
IGUERRER@MSDPO.PCMAIL.INGR.COM

Hans Hauska
Department of Geodesy and
Photogrammetry
Royal Institut of Technology (KTH)
S-100 44 Stockholm, Sweden
HANS@FMI.KTH.SE

Christopher B, Jones
Department of Geography
Univeristy of Cambridge
Downing Place
Cambridge CB2 3EN UK
CBJ@VMS.GEOG.CAM.AC.UK

William Mackaness
Department of Geography
University of Edinburgh
Drummond Street
Edinburgh EH8 9XP Scotland
WILLIAM.MACKANESS@ED.AC.UK

Liqiu Meng
Institut fur Kartographie
University Hannover
Appelstrasse 9A
30167 Hannover 1, Germany

Luanne I. Mulawa
Defense Mapping Agency
3200 South Second Street
St. Louis, Missouri 63118

Michel Rheault (Visitor)
Professor agrege
Departement de Geographie et
Teledetection
Univeriste de Sherbrook
Quebec, J1K 2R1 Canada

Larss Schylberg
Dept. Geodesy and Photogrammetry
Royal Institut of Technology (KTH)
S-100 44 Stockholm, Sweden
LARSS@FMI.KTH.SE

Tapani Sarjaksoki
Dept. Cartography and Geoinformatics
Finnish Geodetic Institut
Ilmalankatu 1A, SF-00240
Helsinki, Finland
TAPANI.SARJAKOSKI@CSC.FI

Terence R. Smith
Department of Computer Science
University of California
Santa Barbara, Califonria 93106
SMITHTR@CS.UCSB.EDU

Steering Committee

Kate Beard
NCGIA/Dept. Surveying Engineering
University of Maine
Orono ME 04469
BEARD@
GROUSE.UMESVE.MAINE.EDU

Barbara Buttenfield
NCGIA/Dept. of Geography
105 Wilkeson, SUNY-Buffalo
Buffalo NY 14261
GEOBABS@
UBVMS.CC.BUFFALO.EDU

Geoffrey Dutton
Harvard Design and Mapping Company
150 Irving Street
Watertown MA 02172
QTM@CUP.PORTAL.COM

Peter Fisher
Midlands Regional Research Lab
Department of Geography
University of Leicester
Leicester LE1 7RH   UK
PFF1@LEICESTER.AC.UK

Roberta Linczowski, Chief
System Center Development Group
Warrior Support Division
Defense Mapping Agency
8613 Lee Highway
Fairfax, VA 22031-2138

David M. Mark
NCGIA/Dept. of Geography
105 Wilkeson, SUNY-Buffalo
Buffalo NY 14261
GEODMM@
UBVMS.CC.BUFFALO.EDU

Robert B. McMaster
Department of Geography
414 Social Sciences Building
University of Minnesota
Minneapolis, MN 55453
MCMASTER@
ATLAS.SOCSCI.UMN.EDU

Jean-Claude Muller
Ruhr-Universiaet Bochum
Fakultaet fuer Geowissenshaften
Universitaetstrasse 150
D-44780 Bochum, Germany

Robert Weibel
Department of Geography
Univeristy of Zurich
Winterthurerstrasse 190
CH-8057, Zurich, Switzerland
WEIBEL@GIS.GEOGR.UNIZH.CH

Rapporteurs

Catherine Dibble, Lead Rapporteur
NCGIA/Dept. Geography
3510 Phelps Hall
University of California
Santa Barbara CA 93106
CDIBBLE@GEOG.UCSB.EDU

Ann Deakin
NCGIA/Dept. of Geography
105 Wilkeson
SUNY-Buffalo
Buffalo NY 14261
V526W8G4@
UBVMS.CC.BUFFALO.EDU

Michael Leitner
NCGIA/Dept. of Geography
105 Wilkeson
SUNY-Buffalo
Buffalo NY 14261
V999RRBY@
UBVMS.CC.BUFFALO.EDU

Steve Parkansky
NCGIA/Dept. of Geography
105 Wilkeson
SUNY-Buffalo
Buffalo NY 14261
SP@GEOG.BUFFALO.EDU

Brandon Plewe
NCGIA/Dept. of Geography
105 Wilkeson
SUNY-Buffalo
Buffalo NY 14261
PLEWE@ACSU.BUFFALO.EDU

Andre Skupin
NCGIA/Dept. of Geography
105 Wilkeson
SUNY-Buffalo
Buffalo NY 14261
SKUPIN@GEOG.BUFFALO.EDU

Chris Weber
NCGIA/Dept. of Geography
105 Wilkeson
SUNY-Buffalo
Buffalo NY 14261
WEBER@
UBVMS.CC.BUFFALO.EDU

Feibing Zhan
NCGIA/Dept. of Geography
105 Wilkeson
SUNY-Buffalo
Buffalo NY 14261
ZHAN@GEOG.BUFFALO.EDU

Appendix C: Papers Accepted for the Specialist Meeting

Affholder, Jean-George	Road Modeling for Generalization
Armstrong, Marc P.	A Coarse-Grained Asynchronous Parallel Approach to the Generation and Evaluation of Map Generalization Alternatives
Bjorke, Jan Terje	Information Theory as a Tool to Formalize Cartographic Knowledge
Buttenfield, Barbara P.	A Research agenda to Formalize Cartographic Knowledge
Collins, Michael J. and Mackaness, W. A.	On the Abstraction of Cartographic Objects from Remotely Sensed Imagery
Dutton, Geoffrey	Toward More Intelligent Spatial Data: Reasons and Rules for Enriching Locational Notation
Elliott, Lynne	An Operational Framework for the Generalization of the Ontario Digital Topographic Data Base to Produce Provincial Series Maps
Fisher, Peter	Formalizing the Evaluation of Cartographic Products
Guerrero, Ignacio	Cartographic Generalization: a Commercial Software Development Perspective
Hauska, Hans and Schylberg, Lars	Simplification of Raster data Bases - When and How
Jones, Christopher B.	Placenames, Cartographic Generalization and Deductive Databases
Mark, David, M.	Separating Spatial and Semantic Aspects of Cartographic Knowledge
McMaster, Robert B.	Formalizing Cartographic Knowledge: Knowledge Acquisition for Map Generalization
Meng, Liqiu and Grunreich, Dietmar	A Note on Knowledge Formalization
Mulawa, Luanne I.	Knowledge Based System Technology in the U.S. Defense Mapping Agency's Digital Production System
Muller, Jean-Claude	Formalization of Cartographic Knowledge: Issues and Strategies
Sarjakoski, Tapani and Lindholm, Mikko	Modeling Interactive Cartographic Communication with Formal Logic and Prolog

Turk, Andrew G. and Mackaness, W. A	The Cognitive Ergonomics of Computer-Assisted Visualization Design
Weibel, Robert	Knowledge Acquisition for Map Generalization: Methods and Prospects

Appendix D

Specialist Meeting Agenda — **24-27 October, 1993**
Formalizing Cartographic Knowledge — **Buffalo, New York**

Saturday 23 Oct
Arrival in Buffalo

7 - 9 pm Informal greeting at the Lobby Bar

University Inn
2401 N. Forest Road
Buffalo NY 14226
(716) 636-7500

Sunday 24 Oct

8:15 am	Continental Breakfast
8:30 am	Introduction and Format - Barbara Buttenfield
10:15 am	Coffee Break
10:30 am	Small Group Breakout - Topic 1 "Why should cartographic knowledge be formalized?"
12:00 pm	Lunch
1:00 pm	Full Group -- Topic 1 Recap Reports of Small Group Discussants
2:45 pm	Coffee Break
3:00 pm	Small Group Breakout - Topic 2 "What methods? How to formalize this knowledge?"
4:30 pm	Session Break-up. Vans depart for Wilkeson at 4:45 pm
5:00 pm	Wine and Cheese Reception, 106 Wilkeson
6:15pm	Vans depart for University Conference Inn
6:30 pm	Dinner at University Conference Inn
8:00 pm	Full Group -- Topic 2 Recap Reports of Small Group Discussants
9:30 pm	Adjourn

Monday 25 Oct

8:15 am	Continental Breakfast
8:30 am	Full Group -- Topic 2 Recap Reports of Small Group Discussants
9:30 am	Presentation "A Knowledge-Based System for Spatial Data" ProfessorTerry Smith, NCGIA-Santa Barbara
10:30 am	Coffee Break
10:45 am	Small Group Breakout - Topic 3 "When (in the cartographic process) should knowledge be formalized?"
12:15 pm	Lunch
1:15 pm	Full Group -- Topic 3 Recap Reports of Small Group Discussants
3:00 pm	Coffee Break
3:15 pm	Vans depart for GIAL Tour and Demos
5:00 pm	Vans depart for Conference Inn
6:15 pm	Vans depart for dinner (guests will be asked to pay for alcohol)

Buffalo Brew Pub
6861 Main Street
Williamsville, NY
(716) 632-0552

Tuesday 26 Oct

8:15 am	Continental Breakfast
8:30 am	Small Group Breakout - Topic 4 "What are the Needs for and Uses of Cartographic Knowledge?"
10:15 am	Coffee Break
10:30 am	Full Group -- Topic 4 Recap Reports of Small Group Discussants
12:00 noon	Lunch
1:15 pm	Vans depart for Niagara Falls field trip Professor Vince Ebert, SUNY-Buffalo Geography
6:00 pm	Dinner at Riverside Inn

Riverside Inn
Lewiston, NY

Wednesday 27 Oct

8:15 am	Continental Breakfast
8:30 am	Discussion of Research Agenda and Priorities "What can be pursued given current state of technology and knowledge?"

10:15 am Coffee Break

10:30 am Summarize Specialist Meeting
Evaluate Specialist Meeting Format

11:30 am Close of Specialist Meeting

(Steering Committee Members are asked to stay on for a working lunch and afternoon meetings, in preparation for GIS/LIS panel session)