NCGIA Initiative 2
"Languages of Spatial Relations"
Closing Report

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Abstract

This report describes the results of NCGIA Research Initiative 2 "Languages of Spatial Relations". It starts by comparing the background and objectives of the initiative as originally planned with our current understanding of the problem following the work carried out during the initiative. It then assesses the work in detail against five criteria: 1. Research Accomplished; 2. Research Agenda Development; 3. Contribution to GIS Education; 4. Implications for Science Policy; and 5. Comments on the Research Initiative Process.

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1. Background

In the early 1980s, members of the GIS community become increasingly aware that a number of the problems experienced with the use of geographic information systems were related to how the geometric aspects of reality were represented, stored, and processed in a computer. Various groups had experienced problems with the programming of spatial algorithms. Users had observed that even commercial systems would produce erroneous results or break down when processing spatial 'overlay' operations, and there was extensive discussion of the 'gaps and sliver' problem resulting from overlay. Most GISs were based on digitized maps and the manipulation of cartographic line drawings. At the same time, the first systems to help car drivers navigate appeared on the market and a discussion of what information drivers would need and how best to present this information started.

In 1986, Andrew Frank and Werner Kuhn published a paper that proposed a simple geometric solution for the modelling of geometric data (Frank and Kuhn,1986), and similar ideas were incorporated into the design of a commercial GIS at the same time. The NSF program in Geography and Regional Sciences awarded a grant for the development of a 'Spatial Theory' in the same year. Around the same time, David Mark was using artificial intelligence techniques to simulate route selection by drivers, based on principles from cognitive science, in order to model ways to provide navigation assistance to drivers (Mark, 1985; Mark and McGranaghan, 1986). While quite disparate at the time, these two lines of research clearly laid a foundation for the work to be undertaken within Initiative 2.

The NSF solicitation for proposals to establish a National Center for Geographic Information and Analysis listed 'general theory of spatial relations and database structures' as a an area of importance, and the proposal of our consortium responded with a proposal that included twelve specific research initiatives. Research Initiative 2 was entitled "Languages of Spatial Relations," and had the following objectives:

1. Identify formal cognitive/semantic models of spatial concepts and relations in natural languages

2. Develop reliable methods for determining reference frames for spatial language

3. Construct formal mathematical/logical models of spatial concepts and relations based on topology and geometry

4. Integrate the two kinds of formal models into a general theory of spatial relations

This report is being tendered after the closing of Initiative 2, late in 1990. We do not mean to suggest, however, that we have solved all aspects of this problem, nor that research on languages of spatial relations at the NCGIA has ended. Nevertheless, it is appropriate to document what has been achieved so far, and what has been learned about the research approaches being employed within the NCGIA.

1.1 Summary of Achievements

In the past 6 years, research on the topic of 'spatial theory' has changed substantially. The research focus has shifted from the technical problem of how to represent geometric figures, and now is firmly centered on the question of how to represent geographic space and geographic phenomena in ways that are consistent with how people understand spatial situations. From the expectation that a general purpose set of modules to treat geometry in a GIS would be possible (the popular "tool-box" approach), many researchers and software developers now are concentrating on the identification of multiple spatial conceptualizations. In fact, it is an open question if a 'unification' across cultures, languages, disciplines, and applications is possible. Originally, the 'spatial theory' was considered a problem of encoding geometry and developing appropriate algorithms. Today the connections between tasks a user wants to perform, the design of the user interface of the system, and spatial concepts is clearly seen (see Frank and Mark, 1991). Couclelis (in press) proposes a theoretical framework for a cognitive geography, and differentiates several levels of spatial cognition.

Some of the notions introduced from cognitive linguistics and substantially adapted to geographic space have found wide acceptance and researchers outside the center are now using them. The 'Image Schemata' of Johnson (1987) currently form the best list of primitives for cognition of space, and are thought to applicable for many purposes (Mark, 1989b). The typology of spaces according to different types of experiences, initially proposed by linguist David Zubin at the Specialist Meeting (see Mark et al., 1989), also has guided much subsequent research.

The approach that we have taken in Research Initiative 2 has successfully brought together mathematical methods and results from cognitive science research, especially cognitive linguistics. The three workshops conducted within the Initiative brought together researchers interested in the topic from a very wide range of disciplines, including linguistics, geography, mathematics, engineering, cartography, computer science, anthropology, and others (see combined participants list in appendix). We are convinced that the interdisciplinary nature of the approach has contributed substantially to the progress made. The concluding meeting of the Research Initiative was a two-week long Advanced Study Institute funded by NATO; again, researchers from the same broad range of disciplines were invited as lecturers. The contributions to this meeting were later collected in a book (Mark and Frank, 1991).

The work conducted under Initiative 2 has not only resulted in a clearer understanding of the problems involved (leading to more detailed research ideas), but also has produced a number of directly useful results. During the specialist meeting, topological relations were identified as a set of spatial relations that had to be formalized. In his dissertation at Maine, Max Egenhofer applied a method previously used for the formalization of time intervals to the problem of two-dimensional spatial relations between extended objects (Egenhofer, 1989b) . This concept was immediately refined and integrated in a commercial GIS. The resulting classification of topological relations was quickly accepted by other researchers and has been used in a number of contexts. Recently, Egenhofer has generalized the method for spatial relations among point, line, and area objects.

The initiative had strong ties to the GIS industry. Results have not only been published in the scientific literature, but also have been rapidly and effectively transfered from the university to software product. We have already mentioned that these definitions of topological relations have been used in a commercial product both to guide the coding effort as well as to explain to the user the definitions used. In another example, the theoretical discussion under Initiative 2 of spatial languages as they apply at the level of the user interface has influenced the design of a recent GIS viewing software by another major company.

As noted above, the formal closing of this initiative does not imply that all problems are resolved or that no further work is required or appropriate. The initiative has been completed in the sense that it has fulfilled the main objectives that were identified initially. Furthermore, new insights have transformed the initial objectives significantly, and a new research plan will be necessary and a new focus recommended. Indeed, Initiative 2 research has continued very directly in two other Initiatives. A major outcome of Initiative 2 was the definition of a new Research Initiative on "User Interfaces for GIS"—Initiative 13 is already underway, and treats closely related topics from the particular perspective of how to present geographic concepts, phenomena, processes, and procedures to the end users of GISs. On the other hand, research initiative 10 "Spatio-Temporal Reasoning and GIS," continues the search for formal models of spatial concepts, and extends the topic to focus on spatial reasoning processes and on the inclusion of time and temporal reasoning.

The remainder of this report addresses five points of discussion posed by a subcommittee of the NCGIA Board of Directors, to be answered in closing reports for Initiatives. Under "Research Accomplished," we describe specific research projects and related activities. Under "Research Agenda Development," we compare and contrast the research agendas for this topic identified before our NCGIA proposal was written, in that proposal, immediately after the Initiative 2 Specialist Meeting, and today. Under "Contribution to GIS Education," we document the high level of involvement by graduate students in all phases of the Initiative. We also make a few comments under the headings of "Science Policy" and "The Research Initiative Process," and close the report with an annotated bibliography of Initiative 2 publications, and a combined list of the 91 people who participated directly in one or more of the three workshops conducted under Initiative 3.

2. Research Accomplished

What do we know now that we did not know before about the questions addressed by the initiative?

The broad aim of Research Initiative 2 has been to identify elements of a fundamental theory of spatial relations. Initiative 2 chose natural language and mathematics as the principal media for investigating and representing this problem; later initiatives might approach the same objective through studies of vision, of spatial behavior, or other topics.

One of the major advances during Initiative 2 was our recognition of the importance of experiential realism, a philosophical position advanced by George Lakoff and Mark Johnson, based on the research of Eleanor Rosch and many others. The mental models that people have of their worlds, and in our case especially of geographic space, must be considered in efforts to build formal or computational models of the world. But these mental models are neither arbitrary nor idiosyncratic, because human bodies, minds, and senses are all essentially similar. Cognitive linguists have developed models of spatial concepts that are remarkably similar to those used in cartography and GIS. Computational systems that deal with geographic data must be able to support several models of the same objects, and relate those models to each other, a result even closer to the core of Initiative 3 ("Multiple Representations") than to Initiative 2. The basic ideas of experiential realism and its importance for formal models of geographic features have been presented in papers at the Ninth International Symposium of Computer-Assisted Cartography (Auto-Carto 9; Mark and Frank, 1989), at a conference in Leicester, England on GIS Design Models (Frank, in press), at the Association of American Geographers' meetings, and in our chapter in the Longman's GIS book (Frank and Mark 1991) and the introduction to the book reporting on the 1990 NATO Advanced Study Institute (Mark and Frank, 1991), as well as in several lectures at various universities and regional meetings.

Another outcome of Initiative 2 has had a more immediate impact on the GIS community. This is the greatly-increased prominence of user interface issues and human-computer interaction (HCI) in the research agenda for geographic information and analysis. Although some research on this topic was underway before the NCGIA was established, Initiative 2 recognized the key relation of this topic to cognitive science and human conceptualizations of space. The concepts that people have about their worlds must be represented in the user interface of the GIS; otherwise, users must perform difficult translations between different conceptualizations of the world. About a quarter of the Initiative 2 publications listed below address the broad topic of user interfaces and query languages, and this theme was developed into a new Research Initiative, number 13, on "User Interfaces for GIS."

Our collaborative work on the topic began, in a sense, as we wrote the original NCGIA proposal to NSF during 1987; however, the period of concentrated effort and resources began with a Specialist Meeting in January 1989. The formal resource period of Initiative 2 concluded with two international meetings in Europe during July 1990, but

our work on the topic can be expected to continue indefinitely. The remainder of this section describes research projects in twelve topic areas within Initiative 2

2.1 Algebras of Spaces and Morphisms between Spaces

During the I-2 Specialist Meeting, a conceptual framework for spatial relationships was identified. Within this framework, there is an algebra for each space describing its properties and morphisms mapping from one space into another. Herring, Egenhofer, and Frank (1990) have investigated this conceptual framework, and one algebra has been defined with Egenhofer's theory of topological relationships. The inclusion relation that defines a partial order between spatial objects has been investigated as part of two master theses (Greasley 1990, Perry 1990). It defines a particular aspect of spatial relations that can be investigated with algebraic methods.

Some spatial relationships exist in more than one algebra, and we have investigated the mappings between the two spaces. John Herring and others have shown in an example how mappings between different algebraic description of space and properties of the space can be defined (Herring et al. 1990). This contribution introduced the notions of mathematical category theory as a method of systematic discussion of algebras related by morphism.

2.2 Formal Definitions of Topological Relationships

In Egenhofer's dissertation, an approach to define binary topological relationships has been proposed. This method is based upon fundamental principles of algebraic topology using the four intersections of the two boundaries and interiors and evaluating them according to topological invariants such as the emptiness/non-emptiness, dimension, or number of separations. An article in the International Journal of Geographical Information Systems lays out the fundamental mathematics and provides the proofs for completeness for n-dimensional objects embedded in n-dimensional space. Also, a joint paper with John Herring (an I-2 participant from Intergraph Corporation) was presented at the Fourth International Symposium on Spatial Data Handling in Zurich. These results have fostered a number of ongoing investigations under Initiative 10, including the inference of new topological information and reasoning over the combination of topological relations, cardinal directions, and approximate distances. In cooperation with Herring, Egenhofer has extended the theory to apply to n-dimensional objects in m-dimensional spaces (m_n). Results were presented at AAG in San Diego and will be published in a computer science journal.

2.3 Query Languages

Interactive query languages are the user's tools to request data from a database. Conventional database query languages, such as SQL, lack the particular functionality to address the retrieval and representation of spatial data. In Egenhofer's Ph.D. thesis, a comprehensive discussion of spatial query language components has been presented. These are: the treatment of complex objects and corresponding (geometric) operations; the graphical representation of query results; interaction with graphically-displayed objects via direct manipulation; the combination of multiple query results in a single rendering; the description of the graphical representation in terms of colors, patterns, and symbols; and the definition of spatial context to be added to the user query asked. An

extension of SQL, including these spatial features as well as the design of a human interface to such a spatial query language is described and then compared with a comprehensive list of previously proposed spatial query languages. The most important aspects of this work have been published in Cartography and GIS and IEEE Transactions on Data and Knowledge Engineering, and in refereed conference proceedings as well as presented at professional conferences (see bibliography, below).

2.4   Computational Models of Locative Expressions

One research theme at Buffalo has examined spatial prepositions and other spatial-relational terms in a cross-linguistic framework. This has had both theoretical and applied sides, and expects to contribute to cognitive science as well as to GIA.

The theoretical side of this has been an examination of spatial prepositions. Annette Herskovits analyzed the role of prepositions in locative expressions in English, and identified about 35 basic "use types" for the prepositions "in", "on", and "at" (Herskovits,1987). The thrust of our Initiative 2 work on this has been to test these use types in a cross-linguistic framework. A cross-linguistically valid list of use types for spatial prepositions (or equivalent grammatical elements) is essential to a computational model of spatial relations. Work has concentrated in particular on the relation involving lateral contiguity, as implied in "Cleveland is on Lake Erie". Preliminary results have been incorporated into a co-authored paper presented by Susan Haller in Zurich (Haller and Mark 1990). During the summer of 1989, Haller, a graduate student in Computer Science at Buffalo, conducted research on computational models of locative expressions. Haller added the generation of locative phrases in response to "where is" questions in the CUBRICON Multi-Media Interface, a DARPA-supported project monitored by the US Air Force. Haller's generation program chooses a reference ('ground') object from among objects currently displayed on a map, and also based on the discourse context as well as the importance of various objects displayed. It then generates a locative phrase relating the figure object to the ground object. The contents of the locative phrase depend on the distance of the figure to the ground and on the current scale of the map. Major findings are summarized in Haller (1989), and Haller and Mark (1990).

More recently, Eleanor Rosch's 'basic-level' concepts and radial category structures have been applied to prepositions in English, Spanish, French, and German. There appear to be central, basic meanings of prepositions that often match up across languages. For example, the same 'best example' situation, "on the table", shows up for on (English), sur (French), sobre (Spanish) and auf (German). In contrast, less central meanings (such as the relation of passengers to buses) may vary more from language to language. Results of this part of the research have not yet been published.

In more practical terms, Matthew McGranaghan has studied the translation of verbal description of locations, as they are typically found on specimen labels in a herbarium, to a coordinate based description of locations, that can be searched and displayed with current GIS technology (McGranaghan, 1991). Systematic biologists and museum collection managers are very interested in such a capability and McGranaghan's continued work on the topic has been supported by the National Science Foundation.

2.5   Driving Directions and Narrative Theory

A major thrust of the work at Buffalo has been to relate the wayfinding directions to more general theories of narrative, including how people understand stories, and how computer programs can be designed to do the same. This may lead to procedures for understanding the spatial aspects of stories in a more general context, to computer integration of geographic texts into GIS, and also could lead to improved verbal directions from vehicle navigation-aid systems (see below). Researchers at Buffalo and Santa Barbara have instituted a long-term study of informal driving directions. Mark collected 31 sets of driving directions in the United States (mostly in Buffalo) by approaching strangers in public places, asking for directions to some other public places (taping the response), and later transcribing them. In Valencia, Spain, Gould collected 22 similar sets of directions (in Spanish). Also, in Los Angeles, Sucharita Gopal collected sets of verbal directions for walking to destinations on the UCLA campus. We have found that the driving directions collected so far exhibit many of the properties of stories and other forms of narrative, including deixis, fictive motion, and metaphor. Also, there appear to be substantial differences in directions produced by male and female subjects, although further research will be needed to verify these results and begin to account for them. Preliminary results were presented in a session of four papers at the 1990 AAG meeting at Toronto, in a paper presented in Zurich (Freundschuh et al. 1990), and in a journal article (Mark and Gould, in press).

2.6   Acquisition and Representation of Spatial Knowledge

A major background theme contributing to the linguistic aspects of spatial relations is the study of spatial knowledge acquisition. Scott Freundschuh (Buffalo) continued his doctoral dissertation research on models of spatial knowledge and on its acquisition. This work was an out-growth of Freundschuh's masters thesis on children's map-use and navigation abilities (Freundschuh 1990). He has completed an experiment which explores how "regularity" of the environment affects both the acquisition of spatial knowledge, and the resulting accuracy of this knowledge in adults. Significant differences can be attributed to geometric structure, and others to whether knowledge was acquired from maps or from field experience. Results appear to indicate that configurational knowledge is acquired more effectively from maps than from experience, and more accurately in a regular (gridded streets) environment than in an irregular (curved streets, cul de sacs) environment. The Ph.D dissertation was successfully defended in October 1991, and results will be published. Freundschuh is now an assistant professor at Memorial University of Newfoundland, and has recently received a research grant from the university to continue his research on spatial knowledge acquisition.

In Maine, a particular problem regarding the representation of detailed spatial data, especially the parcel data, has been under study. Taher Buyong compared a representation that is based on points with known coordinate values (the representation that is traditionally used) with an alternative, where the relative positions of points, as measured in the field, is the controlling information. Different aspect of the concept, from the theoretical bases in adjustment computation to the most practical and economical factors, have been reported in several proceedings papers and summarized in two journal articles. His Ph.D. thesis on this topic has been completed.

2.7 Vehicle Navigation Aid Systems

One area of application for models of spatial knowledge and of the production of spatial language is in the context of provision of real-time navigation assistance for vehicle drivers. Three papers on this topic, written by members of the Initiative 2 research group at Buffalo, appeared in the proceedings of the IEEE-sponsored Vehicle Navigation and Information Systems '89 conference in Toronto, Ontario, September 1989, and were reprinted together as an NCGIA Technical Report (Freundschuh, Gould, and Mark, 1989). Earlier, Gould presented a paper on this topic at the AAG East Lakes Division Meeting in Akron, Ohio, in October 1988; an expanded and revised version of that paper subsequently has been published in a regional geography journal (Gould, 1989b). Results of the research on verbal directions for wayfinding will eventually be applied to vehicle navigation aids.

A group of students at the University of Maine have investigated the differences in spatial concepts to model a highway system, depending on the task. They identified three distinct viewpoints, namely the objects relevant for planning of a trip, the ones relevant to give driving directions and the ones necessary for the actual driving (Timpf et al. 1992). Timothy Nyerges of the University of Washington has independently arrived at a very similar breakdown into three tasks with their related conceptualization, and reported on this at an NCGIA-organized special session at the 1992 Annual Meeting of the Association of American Geographers.

2.8 User Interfaces for GIS

An applied theme in the work at Buffalo was to examine the possible role of cross-linguistic differences in spatial language with regard to user interfaces. Initially, the study emphasized Spanish-English differences. A paper on this work written by Buffalo researchers was presented by Andrew Frank at the Second Latin-American Conference on Geographic Information Systems, in Merida, Venezuela, September 1989 (Mark, Gould, and Nunes, 1989). That paper mixed a linguistic analysis of differences in locative expression with a discussion of cross-linguistic and cross-cultural issues in GIS user interfaces, and has been reprinted as an NCGIA Report. Gould later received a National Science Foundation Dissertation Improvement Grant to continue this research with human-subjects testing in Barcelona (Spain) and Quito (Ecuador) during 1990-91. Gould also organized a special session on user interfaces for the GIS/LIS '89 meeting in Orlando, Florida, December 1989.

Our research on user interfaces led to the conclusion that the spatial concepts applied by the user in understanding a task often will differ from the spatial concepts used by the implementor of a GIS, and this difference may cause major difficulties in the use of GIS. Helen Couclelis presented a paper about a particular instance of this problem, and the results were later published in a journal article (Couclelis, 1991). And, as noted above, "User Interfaces for GIS" was adopted as the 13th Research Initiative of the NCGIA.

2.9 Metaphors for User Interfaces

People use different means to convey and perceive spatial information than they use for non-spatial information. Traditional 'typed' query languages for user-machine interaction have been shown to be cumbersome in a spatial environment where much data is

represented graphically. At Maine, Jeff Jackson (former graduate student), Werner Kuhn, and Max Egenhofer investigated techniques that are appropriate to communicate spatial information. These investigations are based upon the methodologies for user interface design developed in Egenhofer's and Kuhn's dissertations.

Jackson's master's thesis focused on the application of the pan and zoom paradigm to view geographical and abstract information spaces (see Jackson, 1990). He compared different solutions and assessed them, looking for a close parallelism between the conceptual and the actual operations on the user interface level. He and Kuhn have presented their work at a Surveyor's and at a Computer Science Conference. The major results have been a formal definition of user interface metaphors and a new understanding of pan and zoom operations, based on fundamental properties of human vision. The method developed allows to compare interface designs theoretically and eliminate candidate design that will likely confuse users or will be hard to teach. Gary Volta, a graduate student at Maine, has based his master's thesis on their work, and applies the methods in an effort to find new ways of querying non-spatial attributes.

2.10   Visualization of Spatial Information

Michael White (a former graduate student at Maine) worked with Kuhn on the visualization and manipulation of spatial relations and constraints. Kuhn continued this and investigated abstraction mechanisms (classification, generalization and aggregation) as a means to represent metrical relations (e.g. on distances, angles and areas) graphically. This work is based on the Geometric Constraint Calculus from Kuhn's dissertation. Kuhn presented papers on this topic at the International Symposium on Spatial Data Handling in Zurich, and at the American Association of Geographer's meeting in Toronto.

2.11   Spatial Reasoning

Several research projects on spatial reasoning were identified as part of the Initiative 2 research agenda, and begun under this initiative. It concentrated on qualitative description of space and concentrated on cardinal direction and approximate distances. In particular, a special form of the reference frame problem (original objective 2) was studied, and a formal, qualitative set of rules to reason about cardinal directions, like 'North', 'South', etc. (Frank, 1991) was developed. These rules were later combined with reasoning about qualitative distances, like 'Far', 'Near', etc. The results from this initiative led to a redefinition of the NCGIA Research Initiative 10 "Spatio-Temporal Reasoning". First, the initiative provided sufficient insight into spatial reasoning in geographic space to outline a potentially worthwhile research agenda. Second it provided evidence that spatial and temporal reasoning in geographic space should be investigated jointly, as they are closely related conceptually. A preliminary workshop to explore the topic was held, and now an international conference to be held in September 1992 in Pisa, Italy, is under preparation.

2.12   Other Activities

The major International Conference at the end of Initiative 2 was a NATO Advanced Study Institute entitled "Cognitive and Linguistic Aspects of Geographic Space", which was held in Las Navas del Marques, Spain, July 8-20, 1990. The ASI received a grant of

2 million Belgian Francs (about $56,000) from NATO, and also had partial support from the NCGIA. Mark was the Director of the ASI, and Frank was the co-Director. A major product of the ASI was a book, edited by Mark and Frank (1991). Another part of the completion of Initiative 2 was the presentation of several papers at the Fourth International Symposium on Spatial Data Handling in Zurich.

3.   Research Agenda Development

How has the research agenda in this area changed as a consequence of activities of the initiative?

The initial question here is that of a baseline—when did the "activities of the initiative" start, and what was the agenda before that? Our work on this topic, both individually and collaboratively, began in the summer of 1987, shortly after the solicitation for NCGIA was published by NSF. Our first public statements on the agenda can be found in the proceedings of the aptly-titled "International Geographic Information Systems (IGIS) Symposium: The Research Agenda", held in November 1987. In their article, Mark, Svorou, and Zubin (1987) claimed that work in linguistics and cognitive science could contribute to the development of a "general theory of spatial relations". They went on to discuss issues of reference frames in considerable detail, but made no explicit reference to formalisms and mathematical models of space. In a paper entitled "Towards a Spatial Theory" in those same proceedings, Frank (1987) laid out some of the mathematical deficiencies of the way geometry and space were represented on computers. The abstract of that paper ends with the central theme of initiative 2: "It is important that multiple approaches are tried and ultimately combined to best accommodate the concepts human beings use. In cognitive science, efforts to better understand spatial concepts will contribute to a spatial theory" (Frank, 1987, p. 215). The paper though has just one paragraph on the cognitive side of the agenda.

Since 1987, we have stated the research agenda for "Languages of Spatial Relations" at least three times. The first was in our original proposal to NSF, the bulk of which was published in the International Journal of Geographical Information Systems (NCGIA, 1989). That version of the agenda was written during the last quarter of 1987. Next, we published the researchable questions and research agenda that was produced by the January 1989 "Specialist Meeting" for Initiative 2 (Mark, 1989d). And then in the summer of 1992, we participated in the writing of a new research agenda for the NCGIA for 1993-96, as part of our proposal to NSF to extend the NCGIA basic funding for three additional years. If the Initiative is defined narrowly, we should focus on changes between the January 1989 agenda and the present—however, we think it is more appropriate to evaluate the entire process of this agenda from 1987 on.

In the original proposal to NSF (NCGIA, 1989), we discussed a number of research issues under the general heading "Spatial Relations and Database Structures". We stated

three "long-term goals":

- to determine the spatial concepts human beings use

- to develop a coherent spatial theory or comprehensive geometry

- to use this theory to design a comprehensive basis for computer algorithms in GIA/GIS

Needless to say, we have not completely achieved these goals. On close inspection, "the spatial concepts human beings use" turned out to be highly dependent on task, on culture, on language, and on individual differences, thus research is redirected not to search for a single set of concepts, but to consider specific situations and to investigate the concepts relevant for this limited situation. In particular instances, such concepts have been identified and formalizations were achieved and more are underway. To achieve a complete formal theory of spatial relations in cognition is still a worthy goal, but a long way off. However, we have made substantial progress on the fundamentals and elements of such a theory.

First, we differentiate a number of fundamental types of spatial experiences, principally depending on the scale of the objects that a person is interacting with or thinking about, from a table top scale to geographic space (so called "Zubin spaces"; Mark et al., 1989). The crucial differences between spatial concepts at geographic scales, and spatial concepts on the table top, is only just emerging in our thinking on this topic, and has been published in only a preliminary form (Mark, 1992). We have learned that the concepts used to organize our perception of a number of small objects on a table are not the same as the ones used to understand the spatial arrangement of geographic objects (although metaphorical mappings can make 'table top' concepts applicable to geographic space). Research is simplified by the separation of distinct cases which must now be investigated in isolation.

Second, there are strong indications that the 'Image Schemata' of Johnson (1987) provide a good set of candidates for spatial primitives from which other concepts can be built. Now research can concentrate on investigating these image schemata, formalizing them, and describing methods for their combination to form the rich web of complex spatial reasoning patterns that we observe in humans. There is a doctoral dissertation underway in Maine with this goal.

The results achieved so far have been primarily exploited for query processing and for GIS user interface design; complementary investigations include, a doctoral dissertation by Hsueh-cheng Chou, currently in progress in Buffalo, is formalizing a language for certain types of spatial analysis within GIA.

On the side of cognitive impediments to research progress, the fundamental agenda questions really have not changed. We feel that substantial progress has been made in identifying elements of spatial cognition relevant to spatial theory and GIS design, but none of the questions have been answered so completely as to remove the questions from the research agenda. But by no means do we think that this indicates a failure of the Initiative—instead, we view this as confirmation that we were able to identify the major issues in the original proposal. Cross-linguistic studies have revealed common threads and important differences in the ways that geographic space and other spatial relations

are expressed in English, Spanish, French, and German. Work on these aspects continues as independent, post-Initiative 2 research and also within Initiatives 10 ("Spatio-Temporal Reasoning and GIS") and 13 ("User Interfaces for GIS").

The existence of Initiative 13 ("User Interfaces for GIS") is a significant change in the research agenda that came out of Initiative 2. In our original proposal to NSF, exactly one sentence of two lines was devoted explicitly to user interfaces: "Future GISs must include user interfaces that are easy to learn, appear natural to the user, and do not depend on the internal structure of the system." Work within Initiative 2 revealed repeatedly that human factors at the user interface are a major part of the research agenda for GIS/GIA, and in December 1990 this was added to the over-all NCGIA research agenda as the first new post-proposal research initiative.

As a result of the work under Initiative 2, Research Initiative 10 ("Spatio-Temporal Reasoning and GIS") has been substantially redefined. Originally planned as an initiative to investigate "Temporal relations in GIS", it has now a more focused but also more comprehensive objective. Initiative 2 research has convinced us that the understanding of time is strongly linked to the conceptualization of space, and that both temporal and spatial conceptualizations are heavily determined by the problems that are to be solved.

As we noted on page 2 of this report, the original objectives of this research initiative were to:

1) Identify formal cognitive/semantic models of spatial concepts and relations in natural language

2) Develop reliable methods for determining reference frames for spatial language

3) Construct formal mathematical/logical models of spatial concepts and relations based on topology and geometry

4) Integrate the two kinds of formal models into a general theory of spatial relations.

We believe that we have made substantial progress on objectives 1 and 3. On objective 2, some progress was made in exploring qualitative reasoning with distance and cardinal directions that is directly applicable; other groups are also working on this topic. Only the fourth objective remains on the agenda as an important research topic that still requires considerable research effort.

The combination of the formal-mathematical and the cognitive viewpoints has proven to be extremely fruitful, and is far from exhausted. A potential is seen for work that could bridge the current gap between GIS and GIA modelling, and contribute to the integration of the 'vector' (object) and the 'raster' (field) view of space that are prevalent in these two camps. The integration of time (and thus change and motion) into the investigations, especially under Initiative 10, should be an important part of the research agenda over the next few years.

The formalization of spatial primitive relations (for example the 'image schemata') and methods for their combination represents the synthetic approach, and is as promising as the approach that analyzes particular situations of spatial reasoning that reveal the spatial concepts used.

4.   Contribution to GIS Education

How has the education of GIS scientists been enhanced by the initiative?

From the inception of this Research Initiative, graduate students were involved in many aspects of the work under this initiative. Max Egenhofer, Scott Freundschuh, and Taher Buyong, who were involved as graduate students during the early stages of the Initiative have completed their Ph.D.s and are now in university teaching positions. Other graduate students, such as Jeff Jackson, Michael White, Michael Gould are now working in industry. All of the above were graduate students in either Surveying Engineering (Maine) or Geography (Buffalo). Susan Haller is working on a dissertation in Computer Science at Buffalo that involves modelling of driving directions in a natural language production system.

The NATO Advanced Study Institute held in Spain in July 1990 at the end of Initiative 2 may have far-reaching educational impact, since 13 of the meeting's 60 participants were graduate students at the time of the meeting. Six doctoral students from Universities in the United States attended: John Cloud, Department of Geography, University of California, Santa Barbara; Scott Freundschuh, Department of Geography, SUNY Buffalo; Myke Gluck, School of Information Studies, Syracuse University; Michael Gould, Department of Geography, SUNY Buffalo; Susan Haller, Department of Computer Science, SUNY Buffalo; and Dalia Varanka, Department of Geography, University of Wisconsin, Milwaukee. The meeting's participants also included 7 other graduate students, from 6 countries: Ahmet Arslan, Department of Computer Engineering and Information Sciences, Bilkent University, Ankara, Turkey; Francisco Escobar, Departamento de Geografía, Universidad Alcalá de Henares, Spain; Daniel Hernández, Institut für Informatik, Technische Universität München, Germany; Elsa Maria João, Department of Geography, Birkbeck College, University of London, United Kingdom; Jesper Kaae Petersen, Institute of Surveying and Photogrammetry, Technical University of Denmark; Mauricio Ruiz-Pérez, Departament de Ciencies de la Terra, Universitat de les Illes Balears, Spain; and Bor-Wen Tsai, Department of Geography, National Taiwan University.

Myke Gluck, who as noted above is a doctoral student in the School of Information Studies at Syracuse University, wrote (by electronic mail on April 15, 1992) about the influence of his participation on his subsequent research:

> "My participation in Spain under initiative #2 was extremely influential in many ways upon my research:
>
> • methodological concerns and categories as discussed in Spain broadened my outlook as to the range of what constitutes research.
>
> • details and content of the meeting re-enforced and has accelerated my research agenda; I felt that many of the issues I was beginning to address were seen as important by others as well.

- I have presented one paper and have two others accepted for presentation at the annual meetings for the American Association for Information Science; each of these deals with cognitive and linguistic aspects of space. All are reports of empirical studies of how people communicate about space. I have an article on the semiotics of cartography that I am reworking for submission to either Cartographica or other such geography journal. I am in the early stages of organizing special issue for JASIS on spatial information retrieval. These and other research and work are a direct result of the participation at the NATO ASI.

- My dissertation work is a blend of traditional information science concepts such as relevance and satisfaction within the geographic domain.

- Several contacts I made at the meeting have continued and these folks have assisted me in my research by commenting on my work or suggesting outlets for publication.

- In summary, the ASI had and continues to have a very strong influence in the direction of my work as well as the quality and quantity of my output as a scientist."

Initiative 2 has also influenced the curriculum for surveyors at the University of Maine, as one course was restructured to include some of the fundamental results obtained. Also, some of the mathematical results of the initiative have been incorporated into a graduate mathematics course on topology, taught at the University of Maine by Robert Franzosa. It has also influenced the curriculum for geodesy at the Technical University of Vienna, that has been restructured completely, including a new compulsory course on "geometry in GIS" that largely deals with spatial concepts.

5.   Science Policy

Does NCGIA have any recommendations to Academe, Professional Organizations or to NSF on policy decisions that would promote the further advancement of knowledge in the research area addressed by the initiative?

Truly interdisciplinary work has great potential to yield new insight, because the traditional disciplinary limitations can be overcome; thus interdisciplinary work, especially workshops, should be encouraged. We have in the course of this Initiative observed numerous practical barriers that make interdisciplinary work more difficult than necessary, and potentially even dangerous for the individuals involved: it is more difficult to publish outside one's own defined discipline, and thus may make it difficult for an

individual to achieve tenure, especially if departments have narrow guidelines how much and where to publish.

What may be a surprise is that interdisciplinary work between the social and behavioral sciences and the engineering disciplines has at least in this case contributed to a much faster transfer of technology from the researchers' desk to the manufacturer. At the same time, the assessment of shortcomings of current technology has contributed much to the identification the research agenda and its components. Practical problems often expose very fundamental theoretical questions, and theory can contribute enormously to the solution of very practical problems.

6.　　　　The Research Initiative Process

What were the strengths and weaknesses of the research initiative process in facilitating the research in the initiative?

The initiative process worked very well to bring researchers from different disciplines to a meeting of the mind. Meetings with limited amounts of formal presentations— essentially to introduce the relevant contribution from each science—and ample time for focused discussion of individual points can lead to mutual understanding and lay the foundation for collaborative thinking and even collaborative work. The succession of three meetings, with the second and third meetings including a substantial proportion of participants from the preceding meeting(s), helped to form a core group of researchers inside and outside of the NCGIA which reached critical mass. Subsets of this informal college then met several more times by serendipity at professional conferences. Exchange of documents and ideas using electronic mail (either by direct mail or as discussion in the GIS-L forum) also contributed to form this loosely associated group. Approximately two to three years after the first meeting, one can now see an increasing number of researchers from outside the NCGIA conducting research and publishing on this topic.

The practical recommendation is that, if possible, a small workshop should held 6 months to a year before the Specialist Meeting at which a research agenda will be defined. The function of the pre-meeting is to break through some of the interdisciplinary barriers of terminology, philosophy, and methodology, and to provide a core of participants with an understanding of other disciplines to act as a catalyst for interdisciplinary cooperation at the larger and more critical Specialist Meeting.

The value of interdisciplinary workshops, such as the three conducted in relation to Initiative 2, is difficult to assess. In early April 1992, we sent electronic mail to all participants in the workshops associated with Initiative 2, asking them for comments. We received several positive responses, three of which were extensive. The response from one of the graduate student participants, Myke Gluck, has been quoted in section 4, above. The other detailed responses were from cartographer Dr David Medyckyj-Scott, of the Midlands Regional Research Laboratory, Loughborough University of Technology, Leicestershire, England and psychologist Dr. Mark Blades, of the University

of Sheffield. They first met at the NATO ASI in Spain in June of 1990, and began a collaboration which has lead to several co-authored publications:

Medyckyj-Scott, D. and Blades, M. (1990) User's cognitive representations of space; their relevance to the design and use of GIS. Report no 13, Midlands Regional Research Laboratory, University of Leicester, and Loughborough University.

Medyckyj-Scott, D. and Blades, M. (1991). Cognitive representations of space in the design and use of GIS. Proceedings of the Conference on Human Computer Interaction. Edinburgh, August, 1991.

Medyckyj-Scott, D. and Blades, M. (in press). Human spatial cognition: its relevance to the design and use of Spatial Information Systems. Geoforum.

Medyckyj-Scott also reported two other papers influenced by the meeting, and a new collaboration with Dutch researcher Dr. Peter Essens, another ASI participant.

7.   References Cited

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Frank and Mark, 1991. See section 8.3, following.

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Frank, A. U., and Kuhn, W., 1986. Cell Graph: A Provable Correct Method for the Storage of Geometry, Proceedings, Second International Symposium on Spatial Data Handling, Seattle, Washington

Freundschuh et al., 1990. See section 8.4, following.

Freundschuh, Gould, and Mark, 1989. See section 8.4, following.

Gould, 1989b. See section 8.1, following.

Greasley, 1990. See section 8.4, following.

Haller, 1989. See section 8.4, following.

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Mark, Frank, et al., 1989b. See section 8.4, following.

Mark and Gould, in press. See section 8.1, following.

Mark, D. M., and M. McGranaghan, 1986. Effective provision of navigation assistance for drivers: A cognitive science approach. Proceedings, Auto-Carto London, London, England, September 14-19, 2, 399-408.

Mark, D. M., Svorou, S., and Zubin, D. (1987) Spatial terms and spatial concepts: Geographic, cognitive, and linguistic perspectives. Proceedings, International Geographic Information Systems (IGIS) Symposium: The Research Agenda, 2, 101-112.

McGranaghan, 1991. See section 8.4, following.

National Center for Geographic Information and Analysis. (1989) The research plan of the National Center for Geographic Information and Analysis. International Journal of GIS 3: 117-36.

Perry, 1990. See section 8.4, following.

Timpf, S., G. Volta, D. Pollock, A. Frank, and M. Egenhofer, 1992. A Conceptual Model of Wayfinding Using Multiple Levels of Abstraction. GIS, From Space to Territory: Teory and Methods of Spatio-Temporal Reasoning, Pisa, Italy, Lecture Notes in Computer Science, Springer-Verlag, September 1992 (in press).

8. Annotated List of NCGIA Publications Resulting From Initiative 2

8.1. Articles in Refereed Journals

Couclelis, H. (1991) Requirements for planning-relevant GIS: A spatial perspective. Papers in Regional Science 70(1): 9-19.

For a variety of practical, technical, and theoretical reasons, geographic information system (GIS) capabilities are not yet fully attuned to the information needs of planning. This paper focuses on one of the more theoretical sources of existing discrepancies: the differing underlying representations of space in GIS on the one hand, and in much of planning on the other. Indeed, geographic information systems embody an absolute, "container" view of space, whereas the higher-level functions of planning, along with most of regional science and human geography, treat space as "relational". It is suggested that the absolute-relative polarization could be theoretically resolved, and GIS could be made more relevant for strategic planning, through the operationalization of an intermediate conception of space as "proximal".

Couclelis, H. (in press) A Linguistic Theory of Spatial Cognition. Annals of the Association of American Geographers, in press.

Egenhofer, M. (1990a) Interaction with geographic information systems via spatial queries. Journal of Visual Languages and Computing 1(4): 389-413.

In the past, the design of geographic information systems (GISs) has been investigated in a bottom-up manner. At the same time, little consideration has been paid to those system components with which users have immediate contact such as languages to query spatial objects, or the user interface. Considerations about the interaction between the users and spatial data are of primary importance for these issues. The domain of this paper is the investigation of interactive spatial query languages that allow users to pose ad hoc queries against a geographic information system. Its motivation has been the observation that traditional database query languages are insufficient for the treatment of spatial properties. Deficiencies observed include the disregard of user concerns and the lack of support for renderings of query results in forms other than text. This paper presents a methodology for the design of interactive spatial query languages which are embedded into a human interface. The methodology is based upon the users' interactions with spatial objects, which are graphically rendered on a screen, and their pertinent operations. Objects and operations are provided at the conceptual level of the user interface and complemented by the selection of appropriate techniques to interact with spatial objects rendered on a screen. A number of spatial concepts are presented which are crucial for the design of a GIS query language. In a series of interface snapshots their incorporation into a human interface is presented, simulating the interaction between a user and a GIS.

Egenhofer, M. Extending SQL for graphical display. Cartography and Geographic Information Systems (in press).

A language has been designed to describe the cartographic display of query results in a geographic information system. Its syntax is based on SQL, the standard query languages for relational databases. The novel approach is the syntactical separation of database query and display specifications into a query language and graphical presentation language, respectively. Spatial SQL introduces spatial data types and the corresponding spatial relationships, allowing users to inquire about spatial objects in the familiar SELECT—FROM—WHERE form, extended by spatial conditions. The cartographic display of spatial objects selected is directed with the Spatial SQL-based graphical presentation language GPL, so that complex graphic descriptions can be formulated in a language very similar to SQL. GPL contains commands to direct the display of objects, spatial context, the query window, map scale, etc. This allows users to formulate separately queries and display specifications which are integrated during query processing so that an optimized execution strategy in a single step can be achieved. It overcomes the inherent problem of previous spatial query languages which concentrated on the retrieval of data from the database and either tried to integrate the cartographic display into the actual user query or used only default renderings.

Egenhofer, M.J. and **Frank, A.U.** User interface for spatial information systems. Geologisches Jahrbuch (in press).

Computerized information systems that are tailored to spatial data handling play an emerging role as sources of spatially-related information. By managing spatial data in computer systems, new methods are developed to share and exchange spatial information. Human understanding of spatial data and their means of communicating with spatial information systems are the focus of the present investigation. The dualism between operations to manipulate the graphical representation of spatial objects and how these representations are observed will be investigated.

Egenhofer, M. and **Frank, A.U.** (1990) LOBSTER: combining AI and database techniques for GIS. Photogrammetric Engineering and Remote Sensing (Special Issue on Knowledge-Based Expert Systems) 56(6) 919-926.

The powerful logic-based concept of Prolog has been integrated with a database suitable for spatial data handling to form a database query language that is more flexible and powerful than the currently used SQL. This experimental implementation, called LOBSTER, allowed researchers to explore a number of areas of a GIS. Examples from object-oriented modeling, geomorphology, and query optimization show the application of such a language. Problems encountered during the application of LOBSTER include

the absence of consistency checking during input of rules and facts, and the lack of appropriate techniques to detect cyclic rule definitions.

Egenhofer, M. and Franzosa, R. (1991) Point-set topological spatial relations. International Journal of Geographical Information Systems 5(2): 161-174.

Practical needs in the realm of Geographic Information Systems (GISs) have driven the efforts to investigate formal and sound methods to describe spatial relations. After an introduction of the basic ideas and notions of topology, a novel theory of topological spatial relations between sets is developed in which the relations are defined in terms of the intersections of the boundaries and interiors of two sets. By considering empty and non-empty as the values of the intersections, a total of sixteen topological spatial relations are described, each of which can be realized in R2. This set is reduced to nine relations if the sets are restricted to spatial regions, a fairly broad class of subsets of a connected topological space having application to GIS. It is shown that these relations correspond to some of the standard set-theoretic and topological spatial relations between sets such as equality, disjointness, and containment in the interior.

Frank, A. Spatial concepts, geometric data models and data structures. Computers & Geosciences (in press).

There seems to be some uncertainty in the GIS literature regarding the use of the words data model and data structure. There is a clear understanding of these notions in the database literature and it is possible to define analogous terms for GIS: geometric data model and geometric data structure. Geometric data model is used to describe a formalized abstract set of spatial object classes and the operations performed on them. Geometric data structure is then the specific implementation of a geometric data model which fixes the storage structure, utilization, and performance. Humans organize their spatial perceptions using concepts that can be defined as spatial concepts to denote an informal or not directly implementable conceptual structure used to understand space. Examples are given to clarify the theoretical discussion.

Freundschuh, S.M. (1990) Can young children use maps to navigate? Cartographica 27(1): 54-66.

This paper explores preliterate children's abilities to use a map for navigation. Using a map with a route indicated on it, 33 children attempted navigation of an obstacle course. It was found that some 4 year olds, and most 5 year olds were able to use the map to navigate the obstacle course. No formal conclusions were drawn concerning the 6 year olds to perform this task. It was demonstrated that all of the children who participated in this study were capable of extracting the necessary information from a map to enable them to navigate a simple obstacle course.

Goodchild, M.F. Geographical data modeling. Computers and Geosciences (to appear).

Data modeling is defined as the process of discretizing spatial variation, but is often confused with issues of data structure, and driven by available software rather than by a concern for accurate representation. The paper reviews the alternative data models commonly available in spatial databases, and assesses them from the perspective of accurate representation of geographical reality. Extensions are discussed, particularly for three dimensions and time dependence.

Gopal, S. and **Smith, T.R.** (1990) Human way-finding in an urban environment: a performance analysis of a computation process model. Environment and Planning A 22(2): 169-191.

In this paper the characteristics and performance are described of a computational process model (CPM) of human way-finding that is based on psychological models of cognition and experimental data on human way-finding. The model comprises two modules, one for representing objectively a suburban environment and the other for representing the cognitive processes involved in navigation. The CPM is employed to simulate and investigate how spatial knowledge that has been acquired and stored is retrieved and processed in order to plan a path to a given goal.

Gopal, S., Klatzky, R.L. and **Smith, T.R.** (1989) NAVIGATOR - a psychologically based model of environmental learning through navigation. Journal of Environmental Psychology 9(4): 309-331.

This paper presents the NAVIGATOR computational process model described in Gopal and Smith (1990) and stresses its cognitive psychological aspects.

Gould, M.D. (1989b) Exploring cognitive tests as a means to categorize drivers by navigation ability. The East Lakes Geographer 24: 54-62.

Although it has been shown that drivers possess differing levels of ability at navigating large-scale environments, it is not yet known which basic cognitive abilities are direct contributors to navigation. This paper suggests that drivers may be tested for individual differences in key basic cognitive abilities and that navigation ability categories can be inferred from the results. A goal of driver categorization is to better serve individual drivers with navigation assistance such as computerized wayfinding systems or new methods of direction-giving.

Mark, D.M. and **Gould, M.D.** Wayfinding as discourse: A comparison of verbal directions in English and Spanish. Multilingua (in press).

Verbal driving directions were solicited and tape-recorded from 31 English-speaking subjects in North America and from 22 Spanish-speaking subjects in Spain. The transcripts were analyzed within the context of principles of deixis from narrative theory and of cognitive models of spatial language. Both English- and Spanish-speakers provide verbal driving directions utilizing many of the cognitive schemata and linguistic-coding rules discussed recently in the context of narrative comprehension. Verbal driving directions may easily be collected in a natural environment, allowing a unique opportunity to contrast attributes of natural language with results obtained by research in narrative comprehension.

8.2.   Articles in Refereed Proceedings:

Egenhofer, M. (1989a) A formal definition of binary topological relationships. In W. Litwin and H. Shek (eds.) 3rd International Conference on Foundations of Data Organization and Algorithms (FODO), Paris, France Lecture Notes in Computer Science 367, Springer-Verlag, Berlin & New York: 457-472.

The exploration of spatial relationships is a multi-disciplinary effort involving researchers from linguistics, cognitive science, psychology, geography, cartography, semiology, computer science, surveying engineering, and mathematics. Terms like close and far or North and South are not as clearly understood as the standard relationships between integers numbers. The treatment of relationships among spatial objects is an essential ask in geographic data processing and CAD/CAM. Spatial query languages, for example, must offer terms for spatial relationships; spatial database management systems need algorithms to determine relationships. Hence, a formal definition of spatial relationships is necessary to clarify the users' diverse understanding of spatial relationships and to actually deduce relationships among spatial objects. Based upon such formalisms, spatial reasoning inference will be possible. The topological relationships are a specific subset of the large variety of spatial relationships. They are characterized by the property to be preserved under topological transformations, such as translation, rotation, and scaling. A model of topological relations is presented which is based upon fundamental concepts of algebraic topology in combination with set theory. Binary topological relationships may be defined in terms of the boundaries and interiors of the two objects to be compared. A formalism is developed which identifies 16 potential relationships. Prototypes are shown for the eight relationships that may exist between two objects of the same dimension embedded in the corresponding space.

Egenhofer, M. Beyond query languages for geographic databases. In T. Imielinski (ed.), First International Workshop on Nonstandard Queries and Answers, Toulouse, France, July 1991 (in press).

The application of traditional database query languages to geographic databases has been seriously hampered by the lack of functionality to formulate spatial queries and the shortage to represent spatial query results appropriately. It is argued that the interaction between user and database has to be included into the language design to provide for a high-level, interactive database interface language.

Egenhofer, M. (1990b) Manipulating the graphical representation of query results in geographic information systems. In S.K. Chang (ed.), Workshop on Visual Languages, Skokie, Illinois, October 1990: 119-124.

Geographic information systems must frequently present query results in graphical form. Generally, these graphical representations are not in a single, standardized form, but are influenced by the user's individual or corporate working environment. The user may manipulate the graphical representation of query results—not the content of the database—to present the same query result in various ways. Complementary operations are necessary to examine the graphical representation. This dualism between manipulation and examination is investigated and the incorporation of these operations into a human interface is demonstrated.

8.3. Articles, Chapters, and Monographs in other Refereed Outlets

Egenhofer, M. and **Herring, J.** (1991) High-Level spatial data structures. In D. Maguire, M. Goodchild, and D. Rhind (eds.), Geographical Information Systems: Principles and Applications, Longman Scientific and Technical, London, 1: 227-237.

The organization of geometric data in a computer system has drawn much attention in the field of GIS. Since its early beginnings, designers and developers of GIS have been looking for appropriate representations of geometric objects. The semantics of spatial concepts, common to multiple implementations of spatial data structures, and their formalizations are the focus of this chapter. The former specifies what operations can be performed on spatial objects, while the latter defines how these operations are implemented so that they can be actually executed in a computer. This chapter defines data models and data structures, in the past sometimes thought of as high-level and low-level data structures. It proceeds with the definition of a framework to distinguish spatial data models from high-level and low-level spatial data structures. The next sections discuss formalizations of spatial concepts, known from mathematics, followed by examples of spatial data models and spatial data structures. Our conclusion focuses on the integration of different data models under a common user interface.

Frank, A.U. and **Mark, D.M.** (1991) Language issues for GIS. In D.J. Maguire, M.F. Goodchild, and D.W. Rhind (eds.) Geographical Information Systems: Principles and Applications, Longman Scientific and Technical, London, 1: 147-163.

This chapter reviews the major issues involving language and GIS, and thus provides a summary of Initiative 2 for a broad audience of GIS users and researchers. After an introduction, the chapter first discusses cognitive science, especially cognitive linguistics, and then describes the mathematical representation of geographic space in GIS. Query languages, especially with respect to spatial data, are reviewed. Natural language issues discussed include natural language queries and commands, including a discourse model of human-computer interaction; input of geographic data to GIS in text form; and natural language output.

8.4. Articles in Other Outlets

Chou, H.-C. (1991) Design of a language for spatial analysis. Technical Papers, 1991 ACSM-ASPRS Annual Convention, Baltimore 2: 56-64.

Present GISs cannot perform complicated spatial analysis and modeling. In order to extend the analysis capabilities of GIS, it is necessary to design a language for developing spatial analysis functions and procedures. By carefully study of the geographic data models used by spatial analysts, we can design data types and operations that are suitable for geographic analysis. With this high level language, spatial analysts can design and implement their spatial analysis functions more efficiently. The most important step in such a language is to define a proper geographic data model that can represent simple and complex spatial phenomena.

Claussen, H. and **Mark, D.M.** (1991) Vehicle Navigation Systems. Chapter 8 in J.C. Muller, editor, Advances in Cartography. Elsevier: 161-179.

Cartographers have long know that location maps are most useful if the current location is indicated by a "you are here" symbol. Also, such maps are most effective when oriented so that the "away" direction is up. Unfortunately, these map design principles cannot be applied to portable maps (such as road maps) printed on paper or other static media. Computerized vehicle navigation systems now allow such maps to be presented dynamically in moving vehicles, with the current heading "up" and the current position marked. But such computer systems can also provide information to the driver through synthesized speech or through signals. Research is needed to compare the effectiveness of graphic and verbal forms of navigation assistance for drivers. The paper reviews basic and applied dimensions of the topic.

Egenhofer, M. (1989b) Spatial Query Languages. Ph.D. Thesis, University of Maine, Orono, May 1989.

The purpose of this thesis was the investigation of possible languages through which humans may request spatial information stored in computerized information systems, such as geographic information systems or systems for CAD/CAM. The investigations have been motivated by the recognition that traditional database query languages show severe shortcomings when they are applied to spatial data handling. In order to identify the specific concepts of a spatial query language, those concepts have been investigated that humans tend to use when they perceive or exchange spatial information, e.g., graphical representation of spatial data by which humans understand most naturally geometric concepts. The investigations identified a set of eight fundamental spatial concepts to be used as a methodology for the design of spatial query languages. A specific spatial query language has been designed by extending the structured query language SQL with the concepts identified. The new language, called Spatial SQL, is a superset of SQL, i.e., all traditional SQL concepts and commands apply for non-spatial data. Particular effort was put into the treatment of graphical representation with the development of a specific language to describe the graphical renderings of spatial data with colors, patterns, and cartographic symbols; to provide for dynamic graphical representation by adding, removing, or highlighting query results on existing screen drawings; and to establish a spatial context in which graphical results become understandable. Spatial relationships are necessary in spatial query languages to allow users to formulate queries with spatial conditions, such as neighbor, inside, intersect, etc., in combination with other selections on attributes. Particular emphasis was put on topological relationships. Investigations into the mathematical formalisms of concepts in algebraic topology led to a theory of topological relationships which supports the correct processing of such spatial queries. The major results of this study include a methodology for the design of spatial query languages; a demonstration of the extension of an SQL-like language for spatial data handling; the conceptual separation of retrieval and display in a spatial query language; and a formal approach according to which different topological relationships may be identified.

Egenhofer, M. (1991) Deficiencies of SQL for a GIS query language. In D.M. Mark and A.U. Frank, editors, Cognitive and Linguistic Aspects of Geographic Space. Kluwer, Dordrecht (in press).

Numerous proposals have been made to extend the relational database query language SQL to serve as a spatial query language and currently efforts are under way to establish a standardized spatial SQL. Here it is argued that the SQL framework is inappropriate for an interactive spatial query language and an extended spatial SQL is at best a short-term solution. The serious

deficiencies of any spatial SQL are divided into two groups: (1) the severe difficulties to incorporate necessary spatial concepts into SQL such as graphical display and its specification and (2) the lack of power within the relational framework with missing support for complex objects, object identity, meta queries, and non-first-order logic—all crucial when dealing with spatial data.

Egenhofer, M. and Herring, J. (1990) A mathematical framework for the definition of topological relationships. Proceedings, Fourth International Symposium on Spatial Data Handling, Zurich, Switzerland, 2: 803-813.

A new theory of binary topological relationships between n-dimensional spatial objects is presented. Unlike previous approaches, it provides a complete coverage, i.e., any possible constellation between two spatial objects can be described by exactly one of the relationships defined. The formalism is based upon fundamental concepts of algebraic topology and set theory. Spatial regions are modeled as point-sets and the binary topological relationships are then defined in terms of the intersections of the boundaries and interiors of two point-sets. Sixteen potential relationships are identified by considering empty and non-empty intersections. Prototypes are shown for the eight relationships that actually exist between two point-sets embedded in a two-dimensional space. More detailed relationships as refinements of these eight relationships are identified by considering other criteria, such as the number of the individual segments of the four intersections or their dimensions.

Egenhofer, M.J., Kuhn, W., Frank, A. and **McGranaghan, M.,** editors (1991) Cognitive and Linguistic Aspects of Geographic Space: Preprints of three papers by Max J. Egenhofer, Werner Kuhn, Andrew Frank, and Matthew McGranaghan. Report 90-13, National Center for Geographic Information and Analysis, Santa Barbara CA.

The three papers contained in this report address different aspects of the problem of formalizing human communication about geographic space. The three included papers are from the book arising from a NATO Advanced Study Institute held in Spain in July 1990 (see Mark and Frank, 1991).

Freundschuh, S.M. (1989) Does anybody really want or need vehicle navigation aids? Proceedings, VNIS'89, IEEE Conference on Vehicle Navigation and Information Systems, Toronto, September 12-14, 1989: 439-442.

This paper reviews current research on spatial knowledge acquisition in computer science, psychology, and geography, and suggests how these models can enhance VNA development. In addition, the paper discusses current research in cognitive psychology and environmental behavior concerning the presentation of driving instructions to drivers of automobiles. The

development of effective VNAs is not a problem to be solved by only one discipline, but rather requires a multi-disciplinary endeavor. In many cases, research findings in one discipline do support research findings in other disciplines. However, caution should be taken when interpreting these results.

Freundschuh, S.M. (1991) The effect of the pattern of the environment on spatial knowledge acquisition. In D.M. Mark and A.U. Frank, editors, Cognitive and Linguistic Aspects of Geographic Space. Kluwer, Dordrecht (in press).

In the literature, there is a question as to whether or not survey (map-view) knowledge can be acquired from procedural (route) knowledge. Specifically, Thorndyke and Hayes-Roth (1982) contend that in a new environment, procedural knowledge is the basis for navigation, but that survey knowledge is acquired with increased familiarity of that environment. In contrast, Lloyd (1989) suggests that there is no transition from procedural to survey knowledge. This particular study (in progress) addresses the geographical behavior of wayfinding, and more specifically, explores spatial knowledge acquisition and representation. It proposes a model for spatial knowledge based upon previous studies, the pattern of the environment (gridded versus winding or serpentine), and the source of spatial knowledge (direct navigation experience versus maps) and it attempts to discover, through experimental research, the relative accuracy of peoples' configurational knowledge by investigating the roles that arrangement of the environment and source of spatial knowledge play in the acquisition of spatial knowledge.

Freundschuh, S.M., Gopal, S., Gould, M.D., Mark, D.M. and **Couclelis, H.** (1990) Verbal directions for wayfinding: implications for navigation and geographic information and analysis systems. Proceedings, Fourth International Symposium on Spatial Data Handling, Zurich, Switzerland 1: 478-487.

Spoken driving directions were tape-recorded in Buffalo (New York), in two other North American cities, and in Valencia (Spain); spoken directions for walking were obtained on the campus of the University of California at Los Angeles; and a set of written directions were gathered for driving between the same places in Buffalo that were studied above. These directions were analyzed for properties such as: numbers and kinds of landmarks; presence of metrical information such as distance and travel times; deictic and reference frame terms; "style" of directions; and total duration of the direction giving act, and were tabulated against characteristics of the direction-giver. The results have direct implications for the design of vehicle navigation aids and other wayfinding systems, and for verbal aspects of geographic cognition in general.

Freundschuh, S.M., Gould, M.D. and **Mark, D.M.** (1989) Issues in vehicle navigation and information systems. Report 89-15, National Center for Geographic Information and Analysis, Santa Barbara, CA.

This NCGIA report collects and reprints the three singly-authored papers by NCGIA researchers that were presented at VNIS'89, the IEEE-sponsored interdisciplinary conference on Vehicle Navigation and Information Systems, held in Toronto, Ontario, September 12-14, 1989. The papers are listed separately in this section (Freundschuh, 1989; Gould, 1989a; Mark, 1989c), and their contents are described in those individual entries.

Gould, M.D. (1989a) Considering individual cognitive ability in the provision of usable navigation assistance. Proceedings, VNIS'89, IEEE Conference on Vehicle Navigation and Information Systems, Toronto, September 12-14, 1989: 443-447.

The design of vehicle navigation aids (VNAs) has emphasized hardware innovations, and software which is optimized to this hardware. User interfaces to VNAs generally adopt a single mode of presentation of navigation information. This assumes a homogeneous user community and ignores individual variation regarding drivers' levels of spatial cognition, their attention, and other problem solving abilities. Future VNAs should be designed by devoting more attention to the manner in which people structure, recall, and utilize spatial information naturally. Literature on spatial knowledge, individual differences, and human subject categorization is reviewed, and recommendations for the design of future VNAs are made.

Gould, M.D. (1989c) Human factors research and its value to GIS user interface design. Proceedings, GIS/LIS'89, Orlando, Florida 2: 541-550.

User interfaces for both CAD/CAM and database management systems have been optimized to the systems' respective problem domains, partly due to attention to preceding research in human factors. Geographic information systems, however, do not possess user interfaces optimized for the geographic problem solving domain. Greater attention to innovative human factors research and focus upon cognitive science, rather than upon hardware/software aspects of human-computer interaction, will lead to the first generation of spatially-oriented user interfaces for GIS. Directions for future research are suggested.

Gould, M.D. (1989d) Intelligent Picture-based Data Structuring for Vehicle Navigation Research. Unpublished Master's project, Department of Geography, State University of New York at Buffalo.

This project reports a test of a new data structuring environment, the "Intelligent Picture", for use in human navigation research. Tests of spatial

abilities, and prototype user interfaces for vehicle navigation systems, were implemented using Apple's Hypercard rapid prototyping environment.

Gould, M.D. and McGranaghan, M. (1990) Metaphor in geographic information systems. Proceedings, Fourth International Symposium on Spatial Data Handling, Zurich, Switzerland 1: 433-442.

Developers of geographic information systems are beginning to adopt graphical, direct-manipulation user interfaces, usually modeled after the Xerox/Apple "desktop" metaphor. While the desktop, with its associated file and document icons, is perhaps an optimal metaphor for general office automation, it is lacking as an organizing metaphor for GIS. The cartographic map, though an integral part of the GIS interface, is also lacking as an organizing metaphor. Definitions of metaphor are reviewed, to provide insight on its value in a GIS. The role of nesting various levels of metaphor is suggested, the goal of which is to satisfy the system administration, geographic analysis, and cartographic display aspects of GIS.

Greasley, I. (1990) Partially Ordered Sets and Lattices: Correct Models of Spatial Relations for Land Information Systems, Master's Thesis, University of Maine, Orono ME, December 1990.

Land Information Systems (LISs) structure spatial data. Hierarchies have been used to model this structure, with difficulties. In this thesis, I will show that partially ordered sets (posets) and lattices overcome these difficulties. With this in mind, I will then provide the reader with the tools to apply these structures in three steps: (1) presentation of the mathematics of posets and lattices (key topics: cover, cocover, upper ideal, lower ideal, least upper bound (meet or infimum), greatest lower bound (join or supremum), chain, anti-chain, and normal completion); (2) examination of possible applications in LISs (key topics: intersection, boundary, neighborhood, touch, spatial containment, set inclusion); and (3) discuss the implementation of the mathematics presented. The conclusion summarizes the topics discussed and proposes questions for further research.

Haller, S.M. (1989) Spatial relations and locative phrase generation in a map context. Report 89-14, National Center for Geographic Information and Analysis, Santa Barbara CA.

This paper explores the generation of natural language locative phrases with respect to maps and in response to "Where is?" queries by users. Although alternative orientation strategies are possible, we restrict our problem by assuming that the correct ground, (reference point) used for locating a figure, (place being located), is some sort of stationary landmark of sufficient size and importance that is visible on the map. Hence, our problem involves choosing a suitable landmark for the ground, building a knowledge

representation to express the relationship of the figure to the ground, and generating natural language to express that relationship.

Haller, S.M. and Ali, S.S. (1990) Using focus for generating felicitous locative expressions. Proceedings of the 3rd International Conference on Industrial and Engineering Applications of Artificial Intelligence & Expert Systems, ACM Charleston, SC: 472-477.

The paper reports on research concerned with the problem of generating natural language responses to "Where is"-type queries by a user with respect to a map. In ordinary language this is typically achieved by using a locative expression which involves using a preposition (such as in or at) and its object (which serves as a reference point). The selection of an appropriate reference point is important when generating such locative expressions. We attempt to use discourse focus to model the user's mental body position in the selection of an appropriate reference point. This enables the user to use body-oriented inference strategies associated with small scale space to make better sense of the overall spatial organization of the geographic entities and the large scale space of which these geographic entities are a part.

Haller, S.M. and **Mark, D.M.** (1990) Knowledge representation for understanding geographical locatives. Proceedings, Fourth International Symposium on Spatial Data Handling, Zurich, Switzerland 1: 465-477.

This paper addresses the problem of generating natural language to express spatial relations between or among geographic entities, either on a map or in the world. The main focus of the paper is the knowledge representations that are needed to support locative phrase generation, both for English and in a cross-linguistic perspective. Locative phrases expresses a relation not between concrete, "real-world" entities (extensional objects) but rather between conceptual abstractions of those entities, called intensional objects. The multiple representation of, say, a city as sometimes a point and sometimes a polygon is modelled in a semantic network as two (or more) intensional objects related to the same extensional object. The principles are exemplified through a cross-linguistic examination of the situation which in English is expressed in phrases such as: "the house on the lake".

Herring, J., Egenhofer, M. and **Frank, A.U.** (1990) Using category theory to model GIS applications. Proceedings, Fourth International Symposium on Spatial Data Handling, Zurich, Switzerland 2: 820-829.

The theory of models is extremely important to any scientific endeavor. We build formal models of real-world phenomena, analyze these models, and draw conclusions about the real world. In a GIS, analysis can occur within several conceptual models at once, each model representing a different view or paradigm of the data, such as Euclidean geometry, topological, metric,

raster or object models. Their integration into a unifying view is necessary so that users of spatial information may deal with geometric concepts in a manner close to their perception of the "real world". This paper describes a theory of the internal structure of GIS applications based upon the manner in which they integrate different spatial paradigms into a single unified system. Such a description is useful in the investigation both of GIS software functionalities and data structures. This research resulted from discussions among the authors, and others, during the NCGIA's specialist meeting on "Languages for Spatial Relations", which identified a Category Theory as a promising approach to research this integration. The application of this theory lies in (1) GIS and GIS application design and implementation, (2) spatial reasoning and, (3) query processing.

Hsu, P. (1990) An analysis of spatial structure data in landscape for geographic information systems. Proceedings, Fourth International Symposium on Spatial Data Handling, Zurich, Switzerland 2: 888-897.

The spatial structure of the landscape is configuration of the physical open space of a given site with components such as structure, identity, and meaning. It is generally the organization of spaces where topographic characteristics, vegetation mass, built forms, spatial relationships, spatial organizations, and ordering principles interact. A space may be defined as positive or negative, and it may have meaning associated with is such as monumental, vast, suppressive, sacred, etc. Studies have shown that there is a unity and an order common to natural and man-made creations. The discipline inherent in the most ageless and harmonious works of man, are evidence of relatedness of all things. Suggestions have been made that spatial relationships are unique information, but not well understood in any formal sense. Definitions of spatial structure towards perceptual and design oriented aspects are needed to fill the vacuum. This research presents findings on the elements of spatial structure that are most significant to designers and planners. A model of representation is proposed to further understand the perceptual space as part of a spatial structure. In this study model, the neighboring relationships of adjacent land use and the friction between the transportation route and adjacent land use were calculated. In addition, semantic meanings were given to different types of urban functions and temporal characteristics. Thus, perceptual space, which is generally perceived in a natural language, was described in a symbolic data format. The result of this research can be applied in the future development of geographic information systems to provide semantic knowledge information about spaces for urban planning, resource management, and landscape architecture design implementation.

Jackson, J. (1990) Developing an effective human interface for geographical information systems using metaphors. Proceedings, ACSM/ASPRS Annual Convention, Denver, Colorado 3: 117-125.

The emphasis in the design of Geographic Information Systems (GIS) has historically been placed on architecture, database management, and data structures. Unfortunately, little attention has been paid to the development of a system which will effectively manage the interaction between the user and the software. Users of GIS are confronted with vast amounts of data and must be able to process it, concentrating on pertinent information and ignoring the irrelevant. For instance, the tools currently available to deal with the processes of selection and presentation of information (query languages) are difficult to learn and do not present themselves in an intuitive form. In order to further the development of GIS, work has been done in the human-computer interaction area to develop a suitable approach which addresses the problems of scene selection and presentation. This paper describes the advantages of using metaphors to make unfamiliar computer processes correspond to more common situations. More specifically, it discusses a family of pan and zoom metaphors which facilitate scene selection and presentation for GIS.

Kuhn, W. (1990a) Editing spatial relations. Proceedings, Fourth International Symposium on Spatial Data Handling, Zurich, Switzerland 1: 423-432.

Interactive queries, definitions and modifications of spatial relations are hampered by the lack of appropriate ways to visualize these relations. How should distances, angles, areas etc. be represented so that users can see and manipulate them, instead of only seeing their effect on the spatial arrangement of objects? This paper proposes an editing paradigm for interactive operations on spatial relations and suggests an approach to the development of appropriate visual representations

Kuhn, W. (1990b) From constructing towards editing geometry. Proceedings, ACSM/ASPRS Annual Convention, Denver, Colorado 1: 153-164.

With the rapid dissemination of GIS/LIS technology to a wide variety of user communities, human-computer interfaces are becoming more and more important in this area. Existing user interfaces of GIS and LIS emphasize the retrieval and display (i.e. output) of data over the acquisition and editing (i.e. input). The development of powerful and easy to use tools for the latter has been hindered by the lack of a theoretically sound basis. In order to overcome this impediment, the author has developed a language which allows to express general geometric relations in the plane. The language as been successfully used as a basis for the design and implementation of a system for geometric construction tasks. This paper presents the language and shows its application

in the design of a user interface for the acquisition and editing of geometric data.

Kuhn, W. and **Frank, A.U.** (1990) Human interaction with GIS/LIS: editing geometric models. Paper P313.2, Proceedings, FIG, XIX International Congress, Helsinki, Finland 3: 419-434.

The acquisition and interactive manipulation of geometric data are fundamental tasks in the use of geographic and land information systems (GIS/LIS). Most systems offer methods for these tasks which are derived from manual geometric constructions. They tend to have restricted and complex user interfaces. The paper explains these short- comings and proposes an alternative approach, based on the idea of sketching and declaring geomatic constraints.

Mark, D.M. (1989a) Cognitive and linguistic aspects of geographic space: report on a workshop. Miscellaneous Report, National Center for Geographic Information and Analysis, Santa Barbara CA.

This is a report on a workshop entitled "Cognitive and Linguistic Aspects of Geographic Space", held in Buffalo, New York, June 11-12, 1988. The workshop brought together about 20 researchers from geography, linguistics, cognitive science, and engineering, to discuss topics of mutual interest. The Workshop was supported by a "Conferences in the Disciplines" grant from SUNY at Buffalo, by the Faculty of Social Sciences (SUNY/Buffalo), and by the Graduate Research Initiative in Cognitive and Linguistic Sciences (SUNY/Buffalo). Although held before the NCGIA grant was awarded, the workshop represented, in many ways, the start of Initiative 2.

Mark, D.M. (1989b) Cognitive image-schemata for geographic information: relations to user views and GIS interfaces. Proceedings, GIS/LIS'89, Orlando, Florida 2: 551-560.

Image-schemata are idealized conceptual models for human perception and cognition. Many such schemata are spatial, and some are geographic. Users interact with Geographic Information Systems (GISs) in order to learn about, or make decisions about the world. This paper contends that optimal user interfaces for GIS will be based on image-schemata for geographic and other spatial phenomena. The concept of user views also relates to this schema-based approach. An early focus on users and interfaces is important in system design, especially for systems to be used by people from different disciplines, cultures, and languages.

Mark, D.M. (1989c) A conceptual model for vehicle navigation systems. Proceedings, VNIS'89, IEEE Conference on Vehicle Navigation and Information Systems, Toronto, September 12-14, 1989 448-453.

This paper defines a number of terms and concepts related to vehicle navigation, and presents a model which can be used in designing and evaluating components of the navigation system. Support of human navigation has long been a vital function of maps. Recent technological developments have led to new forms of navigation aids, not all of which include maps. Cognitive science studies the workings of the mind, and provides a useful theoretical basis for examining the navigation process and its relation to spatial learning. This provides a conceptual framework for an evaluation of maps and map-alternatives for road navigation.

Mark, D.M. (1989d) Languages of spatial relations: researchable questions & NCGIA research agenda. Report 89-2A, National Center for Geographic Information and Analysis, Santa Barbara CA.

One of the objectives of the Initiative 2 Specialist Meeting was to compile a list of "researchable questions" related to the topic. This Report lists the original set of 65 "Researchable Questions" identified during that meeting. Many of the questions are of a scope similar to a Master's degree thesis; certainly, graduate students looking for thesis, project, or dissertation topics are encouraged to peruse this list and to consider addressing one or more of these questions. The second part of the report contains specific research projects to be conducted at each of the three NCGIA sites contained in the second part of this report.

Mark, D.M. (1991) Representation of geographic space in natural language, minds, culture, and computers. Conference of Latin Americanist Geographers, 1990 Auburn Proceedings, Auburn, Alabama (in press).

Recent research in cognitive science suggests that language and thought are deeply intertwined, and that cognitive models influence perception of the external world, including geographic space. People with different natural languages probably conceptualize at least some aspects of their worlds differently. And the more different the languages, the more likely these differences will be. 'Culture' may be an even greater source of differences in individual cognitive models of environment, but cultural differences are often correlated with linguistic ones. Recent developments in cognitive science and in GIS provide Latinamericanists with many new concepts and tools that should be useful to them in both theoretical and applied research. In the paper, the author raises some issues which are believed to be are important, and which may form a basis for discussion. The paper is organized around the following bipolar contrasts: Cognition and Behavior; Language and Cognition; Objectivism and Reality; Objectivism and Culture; and GIS and Latin America.

Mark, D.M. and **Frank, A.U.** (1989) Concepts of space and spatial language. Proceedings, Ninth International Symposium on Computer-Assisted Cartography (Auto-Carto 9), Baltimore, MD 538-556.

Development of a comprehensive model of spatial relations is important to improved geographic information and analysis systems, and also to cognitive science and behavioral geography. This paper first reviews concepts of space. A critical distinction is between small-scale spaces, whose geometry can be directly perceived, and large-scale space, which can be perceived only in relatively small parts. Fundamental terms for spatial relations often are based on concepts from small-scale space, and are metaphorically extended to large-scale (geographic) space. Reference frames, which form an important basis both for spatial language and for spatial reasoning, are discussed.

Mark, D.M. and **Frank, A.U.** (1990) Language, cognitive science, and geographic information systems. Report 90-10, National Center for Geographic Information and Analysis, Santa Barbara CA.

This technical report includes two articles. The first is entitled "Language, Cognition, and the Representation of Geographic Space", by D.M. Mark and A.U. Frank, and is under revision for submission to a journal. The other is Frank and Mark's "Language issues for GIS", forthcoming in Maguire, Goodchild, and Rhind's edited book, Geographical Information Systems: Principles and Applications, described elsewhere in this section. "Language, Cognition, and the Representation of Geographic Space" is an overview of the more theoretical side of Initiative 2. Development of a comprehensive model of spatial relations is important to improved geographic information and analysis systems, and also to cognitive science and behavioral geography. The paper first describes and discusses experiential realism, a new synthesis of mental representations of concepts and categories arising from cognitive science. It then reviews concepts of space, both in general, and for geographic space in particular. A critical distinction is between small-scale spaces, whose geometry can be directly perceived through vision and other senses, and large-scale space, which can be perceived only in relatively small parts. Fundamental terms for spatial relations often are based on concepts from small-scale space, and are metaphorically extended to large-scale (geographic) space.

Mark, D.M. and **Frank, A.U.**, editors (1991) Cognitive and Linguistic Aspects of Geographic Space. Kluwer, Dordrecht (camera-ready book manuscript sent to Kluwer, September 1991).

This book presents an edited collection of 28 articles by participants in a NATO Advanced Study Institute held in Spain during July 1990. The editors wrote the preface and introduction to the book, and extended introductions to

each of the six major sections of the book. Five chapters were authored by NCGIA personnel.

Mark, D.M., Frank, A.U., Egenhofer, M.J., Freundschuh, S.M., McGranaghan, M. and **White, R.M.** (1989) Languages of spatial relations: Initiative two specialist meeting report. Report 89-2, National Center for Geographic Information and Analysis, Santa Barbara CA.

GIS progress is impeded in many cases by poorly-designed or inappropriate user interfaces and query languages. Also, some types of geographic data are in text form, and their entry into a GIS requires either language analysis or a great deal of human effort. Cognitive science provides a framework for relating geographic language, and spatial relations and concepts, to GIS. This report is essentially a synthesized transcript of what was said during the Specialist Meeting for NCGIA Research Initiative 2. That meeting brought together geographers, cognitive linguists, engineers, computer scientists, and others. Working groups identified a research agenda for the topic.

Mark, D.M., Gould, M.D., Freundschuh, S.M., Egenhofer, M.J., Kuhn, W., McGranaghan, M. and Svorou, S. (1989) Working bibliography on "Languages of Spatial Relations". Report 89-10, National Center for Geographic Information and Analysis, Santa Barbara CA.

This report contains over 500 references on "Languages of Spatial Relations" and related topics. The core focuses on linguistic studies of how natural languages represent and express objects and relations in geographic space, and on GIS data structures. The "related topics" include selected or key papers on human spatial cognition and learning, and on human-computer interfaces. The bibliography is intended to be the first edition of a "working bibliography" of this, the topic of NCGIA Research Initiative 2.

Mark, D.M., Gould, M.D. and Nunes, J. (1989) Spatial language and geographic information systems: cross-linguistic issues. Proceedings, 2nd Latin American Conference on Applications of Geographic Information Systems, Merida, Venezuela 105-130 (this paper was reprinted as NCGIA Report 90-2).

Most existing GISs were designed by English or German speakers. Since languages impose structure on the cognition and perception of space, GIS data models, query languages, and user interfaces probably contain artifacts of the language spoken by their designers. Natural language studies are important because GISs of the future will have to handle natural language in a number of situations. This paper expands on general principles of cognitive linguistics, with emphasis on cross linguistic issues. Then, it reviews the primitive geographic relations represented in most Indo European languages by prepositions, concentrating on differences between English and Spanish.

McGranaghan, M. (1991) Matching representations of geographic locations. In D.M. Mark and A.U. Frank, editors, Cognitive and Linguistic Aspects of Geographic Space. Kluwer, Dordrecht (in press).

Many references to geographic locations are made linguistically, using words to describe the location in terms of objects in the landscape and the relations among them. In order to attach coordinates to these locations, one must be able to identify them in a database which contains representations of the objects and relations as well as coordinates for these features. This article assesses the correspondence between the features used in describing locations in an herbarium collection and those represented in standard cartographic databases. An alternative representation for geographic data is suggested.

Neal, J.M., Thileman, C.Y., Dobes, Z., **Haller, S.M.** and **Shapiro, S.C.** Natural language with integrated deictic and graphic gestures. Proceedings of the DARPA Speech and Natural Language Workshop. Morgan Kaufmann, Inc., Los Altos CA (in press).

People frequently and effectively integrate deictic (pointing) gestures with speech (natural language, NL) when conducting human-to-human dialogue. Similar multi-modal communication can facilitate human interaction with computers. As part of the CUBRICON project, we are developing NL processing technology that incorporates deictic and graphic gestures with simultaneous coordinated NL for both user inputs and system-generated outputs. The domain for the research is tactical Air Force mission planning, and involves geographic data and problems, and the generation of locative expressions.

Perry, L. (1990) Extending (finite) partially ordered sets to lattices: an incremental approach. Master's Thesis, University of Maine, Orono ME, August 1990.

Partially ordered sets and lattices an be used to model the relationships that exist in many real-world situations. However, the canonical method of extending a partially ordered set or "poset" to a lattice is much too ineffective for use in practical applications as it always requires on the order of 2^n calculations for a poset of size n, regardless of the size of the resulting lattice. In this paper, a new, incremental approach to extend finite posets (as would arise in practice) is described and compared with the usual method. It is shown that the two constructions yield identical lattices, but that the computational complexity of the incremental approach is polynomial in the size of the final lattice, making it more efficient that the canonical method in certain cases.

Rapaport, W. J., Segal, E. M., **Shapiro, S.C., Zubin, D. A.,** Bruder, G. A., Duchan, J. F. and **Mark, D. M.** (1989) Cognitive and computer systems for understanding narrative text. Technical Report 89-07, Department of Computer Science, University at Buffalo, Buffalo NY.

This report describes a long-term project to develop a computational theory of how humans understand narrative text. The theory will be informed by joint research from the viewpoints of linguistics, cognitive psychology, language acquisition, literary theory, geography, philosophy, and artificial intelligence. The report describes the knowledge representation and natural language processing issues involved in the computational implementation of the theory. It includes a section by Mark on how readers might develop an understanding of the geographical space in which a story occurs.

Steiner, D., Egenhofer, M. J. and **Frank, A. U.** (1989) An object-oriented cartographic output package. Technical Papers, ASPRS/ACM Annual Convention, Baltimore,MD 5: 104-113.

An object-oriented cartographic output package is proposed as a solution to the shortcomings of existing procedural graphics packages for the display of query responses to Geographic Information Systems. This paper compares the object-oriented approach with current procedural approaches for computer cartography. The concepts of data abstraction and the application of combinatorial topology to modelling graphic objects, fundamental to an object-oriented treatment of geometry, are discussed. Spatial objects can be represented by a variety of different symbols depending on the context of the map. The object-oriented approach facilitates this variation of symbology. The design and implementation of a prototype cartographic output package based on this approach are introduced.

**9.   Participants in the Three Workshops Held in Conjunction
        With Initiative 2**

Three workshops were held in conjunction with the research initiative on "Languages of Spatial Relations;" these were attended by a total of 91 different people. In June 1988, a 2-day workshop involving 23 people was held in Buffalo, New York (Mark, 1988). This was before the NCGIA grant was awarded, but was held because of our interest in the topic that developed as we wrote the proposal.   The workshop was an important preparatory step for Initiative 2. Interdisciplinary workshops must overcome disciplinary boundaries such as differences in terminology, in research methods, and in philosophical stances. Ten participants in the June workshop, from four key disciplines, attended the actual "Specialist Meeting" for I-2. We believe that the highly interdisciplinary specialist meeting was successful in part due to this preparation.

The Specialist Meeting was held in Santa Barbara, California, in January 1989. There were 28 participants at the meeting, 10 of who had (as noted above) attended the June 1988 Buffalo workshop. Then, in July 1990, a larger Advanced Study Institute, with 60 participants, was held in Spain under NATO sponsorship to 'complete' Initiative 2 and disseminate the results. Ten of those participants had been at one or the other of the earlier workshops, but 50 individuals were at their first I-2 meeting.

The following section lists all 91 people who participated in these workshops, and indicates which workshop(s) they attended. The column marked "Pre" referes to the June 1988 workshop; "SM" is the Specialist Meeting, and "NATO" is the Advanced Study Institute. The 17 individuals who were graduate students at the time of their participation are marked with asterisks (*).

Participants in the Initiative 2 Specialist Meeting ("SM"), January 1989

Pre	**SM**	**NATO**		
-	X	-	Mark Ashworth	Prime Canada Ltd, 513 McNicoll Avenue, Willowdale, Ontario, Canada M2H 2C9
X	X	-	Helen Couclelis	Department of Geography, University of California, Santa Barbara, California 93106
-	X	X	Max Egenhofer*	NCGIA, Department of Surveying Engineering, University of Maine, Orono, Maine 04469
-	X	-	David Embley	Department of Computer Science, Brigham Young University, Provo, Utah 84602
-	X	-	Robin Fegeas	US Geological Survey, 597 National Center, Reston, Virginia 22092

-	X	-	Andreas Flury*	Department of Geography, University of California, Santa Barbara, California 93106
X	X	X	Andrew U. Frank	NCGIA, Department of Surveying Engineering, University of Maine, Orono, Maine 04469
X	X	X	Scott Freundschuh*	NCGIA, Department of Geography, SUNY at Buffalo, Buffalo, New York 14260
-	X	-	Reginald G. Golledge	Department of Geography, University of California, Santa Barbara, California 93106
-	X	-	Sucharita Gopal	Department of Geography, University of California, Santa Barbara, California 93106
-	X	-	J. Armando Guevara	Environmental Systems Research Institute, Inc., 380 New York Street, Redlands, California 92373
-	X	X	John R. Herring	Intergraph Corporation, M.S. IW17A2, One Madison Industrial Park, Huntsville, Alabama 35807-4201
-	X	-	Ewald Lang	University Wuppertal, FB4 Gausstr. 20, D-5600 Wuppertal, West Germany
-	X	-	Jack Loomis	Department of Psychology, University of California, Santa Barbara, California 93106
X	X	X	David M. Mark	NCGIA, Department of Geography, SUNY at Buffalo, Buffalo, New York 14260
X	X	X	Matthew McGranaghan	Department of Geography, University of Hawaii at Manoa, Honolulu, Hawaii 96822
-	X	-	Tim Nyerges	Department of Geography, University of Washington, Seattle, Washington 98195
X	X	-	Bruce Palmer	Digital Equipment Corporation, 2 Iron Way (MR03-1 /E13), Box 1003, Marlborough, Massachusetts 01752
-	X	-	Donna J. Peuquet	Department of Geography, Pennsylvania State University, University Park, Pennsylvania 16802

-	X	-	Jan W. Van Roessel	EROS Data Center, TGS Technology, Inc., Sioux Falls, South Dakota 57198
X	X	-	Stuart Shapiro	Department of Computer Science, SUNY at Buffalo, Buffalo, New York 14260
-	X	-	Terence R. Smith	Department of Geography, University of California, Santa Barbara, California 93106
-	X	-	Steve Smyth	Spatial Data Research, Inc., Suite 900, 10900 N.E. Eighth Street, PO Box 1823, Bellevue, WA 98009-1823
X	X	-	Soteria Svorou	2323 Van Ness, Apt #202, San Francisco, California 94109
X	X	X	Len Talmy	Program in Cognitive Science, University of California, Berkeley, California 94720
-	X	-	Waldo Tobler	Department of Geography, University of California, Santa Barbara, California 93106
-	X	-	R. Michael White*	Department of Surveying Engineering, University of Maine, Orono, Maine 04469
X	X	-	David Zubin	Department of Linguistics, University at Buffalo, Buffalo, New York 14260

Participants in June 1988 Buffalo Workshop who did not attend the Specialist Meeting

Pre	SM	NATO		
X	-	-	Gail Bruder	Department of Psychology, SUNY at Buffalo, Buffalo, New York 14260
X	-	-	Roger Downs	Department of Geography, Pennsylvania State University, University Park PA 16802
X	-	X	Geoffrey Edwards	Centre de Géomatique, Department des Sciences Géodesiques et Télédétection, Université Laval, Ste-Foy, Québec, G1K 7P4, Canada
X	-	-	Peter Gould	Department of Geography, Pennsylvania State University, University Park PA 16802

Pre	SM	NATO		
X	-	-	Daniel A. Griffith	Department of Geography, 343 H.B. Crouse Hall, Syracuse University, Syracuse, NY 13224-1160
X	-	-	Leonard Guelke	Department of Geography, University of Waterloo, Waterloo Ontario CANADA N2L 3G1
X	-	X	C. Grant Head	Department of Geography, Wilfrid Laurier University, Waterloo Ontario CANADA N2L 3C5
X	-	-	Annette Herskovits	Department of Computer Science, Wellesley College, Wellesley, Massachusets
X	-	X	Werner Kuhn	NCGIA, Department of Surveying and Engineering, University of Maine, Orono, Maine 04469
X	-	-	Jack Kulas	Department of Computer Science, University of Idaho, Moscow, Idaho 83843
X	-	-	Mark MacLennan*	Department of Geography, SUNY at Buffalo, Buffalo, New York 14260
X	-	-	John Pipkin	Department of Geography, SUNY at Albany, Albany, NY 12222
X	-	-	Erwin Segal	Department of Psychology, SUNY at Buffalo, Buffalo, New York 14260

NATO ASI Participants who did not attend either of the earlier workshops

Pre	SM	NATO		
-	-	X	Ahmet Arslan*	Department of Computer Engineering and Information Sciences, Bilkent University, P.O. Box 8, Maltepe, 06572 Ankara, Turkey
-	-	X	Elaine M. Bjorkland	Department of Geography, University of Western Ontario, London, Ontario, N6A 5C2, Canada
-	-	X	Mark Blades	Department of Psychology, The University of Sheffield, Sheffield S10 2TN, United Kingdom
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