LANGUAGES OF SPATIAL RELATIONS: RESEARCHABLE QUESTIONS & NCGIA RESEARCH AGENDA

Report compiled and edited by

David M. Mark
NCGIA, Department of Geography,
SUNY at Buffalo, Buffalo, NY 14260

National Center for Geographic Information and Analysis

Report 89-2A

Table of Contents

Preface and Acknowledgements

This report summarizes the "researchable questions" that arose from a workshop entitled "Languages of Spatial Relations", held in Goleta and Montecito, California, January 15-19, 1989. It also lists the research agenda for the NCGIA on this topic. The compiler wishes to thank the rapporteurs of the meeting, Max Egenhofer, Scott Freundschuh, Matt McGranaghan, and Mike White, as well as the Working Group leaders and other I-2 Specialist Meeting participants, for assembling most of the "researchable questions"; Max Egenhofer and Helen Couclelis for supplying, respectively, the Maine and Santa Barbara research agendas; and I-2 co-leader Andrew Frank for comments on an earlier draft of this report. The meeting, and this report, represent parts of Research Initiative #2, "Languages of Spatial Relations", of the National Center for Geographic Information and Analysis, supported by a grant from the National Science Foundation (SES-88-10917); support by NSF is gratefully acknowledged.

INTRODUCTION

In January of 1989, the National Center for Geographic Information and Analysis (NCGIA) organized and hosted a workshop entitled "Languages of Spatial Relations". This meeting was the "Specialist Meeting" for NCGIA Research Initiative #2, which has the same title as the workshop. The research mission of the NCGIA involves removing impediments to the analysis and use of geographic information in theoretical and applied research; one group of conceptual and technical impediments centers around language and languages.

The Specialist Meeting brought together geographers, cognitive linguists, computer scientists, engineers, and others in three days of interdisciplinary discussions on the representation of geographic space-- representation in language, in thought, and in computers. One theme of the meeting was that geographic information systems (GIS) must have at least some capabilities to deal with natural language. Automated input of geographic data in text form; natural language queries; production of natural language for navigation assistance, and for more general problems-- these are a few concrete examples. Principles of language and cognition are especially relevant for the design of user interfaces. Another theme is that data models and data structures which are compatible with cognitive models are likely to facilitate system use and especially interface design. Human natural languages hold important clues to fundamental spatial relations, objects, and concepts. Careful design following cross-linguistic analysis can help minimize the problems of transferring GIS technology to non-English- speaking situations, especially in developing countries.

One of the objectives of the Specialist Meeting was to compile a list of "researchable questions" related to the topic, to be included in the report on the meeting. These questions were to emphasize problems that could be tackled within a 12-24 month period, by Center personnel, by other Specialist Meeting participants, and/or by the research community at large. Unfortunately, the compilation process was delayed, and so the report on events at the meeting was published recently (as NCGIA Report 89-2) without this list of questions, organized and grouped by topics. (Most of these questions did appear in Report 89-2, under the Working Group reports, pp. 37-46.) This Report lists the original set of 65 "Researchable Questions" identified during the I-2 Specialist Meeting. The text of these questions is based on small group discussions, and on the reports of the leaders of those discussion groups. Many of these questions are of a scope similar to a Master's degree thesis, although many are much more involved, whereas others are more simple. 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.

In the months following the Specialist Meeting, research personnel at Buffalo, Maine, and Santa Barbara considered these questions, together with other issues raised at and after the Specialist Meeting, and combined them with personal research agendas, backgrounds, and interests to produce a list of specific research projects to be conducted at each of the three NCGIA sites. This Report presents these specific projects, which are expected to represent the bulk of the deliverable research to be conducted directly under NCGIA Initiative #2.

LIST OF I-2 PARTICIPANTS

Mark Ashworth, Prime Wild GIS Inc.
Helen Couclelis, Department of Geography, University of California, Santa Barbara

Max Egenhofer, Department of Surveying Engineering, University of Maine
David Embley, Department of Computer Science, Brigham Young University
Robin Fegeas, US Geological Survey, Reston, Virginia
Andreas Flury, Department of Geography, University of California, Santa Barbara
Andrew U. Frank, Department of Surveying Engineering, University of Maine
Scott Freundschuh, Department of Geography, SUNY at Buffalo
Reginald G. Golledge, Department of Geography, University of California, Santa Barbara
Sucharita, Gopal , Department of Geography, University of California, Santa Barbara
J. Armando Guevara, Environmental Systems Research Institute, Inc.
John R. Herring, Intergraph Corporation
Ewald Lang, Linguistics, University Wuppertal, West Germany
Jack Loomis, Department of Psychology, University of California, Santa Barbara
David M. Mark, Department of Geography, SUNY at Buffalo
Matthew McGranaghan, Department of Geography, University of Hawaii at Manoa
Tim Nyerges, Department of Geography, University of Washington
Bruce Palmer, Digital Equipment Corporation
Donna J. Peuquet, Department of Geography, Pennsylvania State University
Jan W. van Roessel, EROS Data Center, TGS Technology, Inc.
Stuart Shapiro, Department of Computer Science, SUNY at Buffalo
Terence R. Smith, Department of Geography, University of California, Santa Barbara
Steve Smyth, Spatial Data Research, Inc.
Soteria Svorou, Linguist, San Francisco, California
Len Talmy, Program in Cognitive Science, University of California, Berkeley
Waldo Tobler, Department of Geography, University of California, Santa Barbara
R. Michael White, Department of Surveying Engineering, University of Maine
David Zubin, Department of Linguistics, University at Buffalo

"RESEARCHABLE QUESTIONS" IDENTIFIED AT THE I-2 SPECIALIST MEETING

A. FORMALISMS FOR GEOGRAPHIC INFORMATION AND INFERENCING

1. Herring proposed to discover operators and algebras for specific spaces, classify the operators which are valid, and look at how the operators behave with the Boolean algebra. This research can be based upon the experience in the topological space of Egenhofer and Herring. They developed a defined a set of fundamental binary topological relationships based upon topological properties. Several approaches are possible:

   a assign properties to relationships. Use terms proposed by Smith in his presentation (transitive, symmetric, reflexive, etc.)

   b define unary operators

   c reduce the operators to a minimal set

   d investigate convenience operators. The minimal set of operators does not necessarily contain the most convenient operators used for instance in query languages; however, such operators can be defined as combination of the fundamental operators. The properties of such convenience operators must then be derived from the combinations.

   e based upon this experience, examine in other spaces classes of operations. It is now necessary to describe the properties of these operations.

2. Discover morphisms between spaces (Herring). This can be approached by identifying operators which do similar things in different spaces. For example, state a metric problem in a metric space and a similar problem in topological space, and then compare whether the two operators are the same.

3. Study which problems can be solved by using the morphisms to map into another space, solve the problem there, and then map back. An example is the dilation operation which can be solved easily in a raster space, but is difficult to be solved in a vector space.

4. Combination of spaces by combining algebras, so-called cross-morphisms (Herring). This question relates to the "Reno - San Diego" problem where a state is generally east of another state, but a city, contained in the first state, is not east of a city contained in the second state. The approach is to take separate operators and combine them. This combination will define a new space in which inferencing may be different from reasoning in the separate spaces. One approach would use image-schemas, combining the part-whole image-schema with geographic hierarchy, which usually works but occasionally produces errors such as "Reno is east of San Diego". Defeasable logic might be used to express

   (a c A) + (b c B) + East_Of(B,A)= =TRUE --> East_Of(b,a)

5. Optimize what to execute where, i.e., in which space, based upon the collection of algebras (Embley). This question must consider the implementation of the operators and cost algorithms must be developed. Costs are based upon the complexity of each operation and must consider how expensive the morphisms are. Context may be important.

6. Inferencing about non-geometric properties (Van Roessel). Van Roessel emphasized that GIS contain not only spatial, but also non-spatial properties the inference about which is related to the inference about geometric properties. The problem can be approached by taking an existing algebra and integrating the spatial algebra, for example as the cross product of algebras. Smith proposed a literature search based upon the new Ullman book on knowledge and databases.

7. Geometric inferencing from attribute data (Herring and Peuquet). This research should investigate how spatial knowledge can be derived from attribute data. Examples for such possibilities are address schemes, like in Washington D.C. or in Salt Lake City, Utah, where the house number gives spatial information.

8. Effects on inferencing under scale changes (Herring). This problem may be attacked using an approach similar to the investigations of different space.

9. Inference between objects in 2D and 2 1/2 D representation, and 2 1/2D and 3D (Egenhofer). The question to investigate is what can be achieved by representing spatial knowledge in a more complex model, and what cannot.

10. How can one deal with over-determined structures (Egenhofer and White)? This question was motivated by the ability to reason about redundant metric by using least squares adjustments and statistical methods. The goal should be to identify possible solutions for the detection of over-determined or contradicting structures, such as topology.

11. Herring suggested investigating the relations between metric and quasi-metric spaces. Embley saw three directions: 1) objects, ontology; 2) view space (e.g. topological, quasi-metric, metric); 3) spatial relations (operators). These are not necessarily orthogonal, and an axis may contain other sub-axes. Shapiro suggested the idea of separating operators according to space.

12. Herring suggested researching the integration problem in raster/vector GIS, i.e. how to make this invisible to the user.

B. IMAGE-SCHEMAS and SCHEMA-DRIVEN PERCEPTION AND COGNITION OF SPACE AND MAPS

13. What are the translations between graphical language and natural language? What role do image-schemas play in this?

14. What can image schemas *not* model? (i.e., what spatial situations cannot be modeled by image schemas?)

15. Investigate schema-driven bulk-reduction (gestalt) for visual and natural language.

Map and Airphoto Image-Schemas

16. What is the difference in imaging schemas between viewing maps and viewing scenes in particular contexts?

17. What are the mental schemas that air photo interpreters use to produce an encoding of features in specific contexts? This includes schernatizing for bulk reduction as identified in the "universal construct" group discussion.

18. What are the schemas that map readers use to interpret maps, particularly those related to schematizing for bulk reduction.

19. How do the schemas of the cartographer match the schemas of the map user? It was suggested that this topic sounded like an attempt to structure the communication process as depicted in the cartographic communication models.

20. How do we capture the schemas of the cartographer and/or the map user? It was suggested that Cue analysis be used to uncover the schemas.

21. What are the components of the map user's image-schemas so that a system would know when to generate a orthographic/perspective and when to produce a planimetric view?

C. VISUAL GRAMMARS; GESTALT AND CANNONICAL PROPERTIES OF SPATIAL OBJECTS

22. What are the influences of size distortion on the meaning of information in cartograms? Do people use a linear or perceptual scaling when they interpret cartograms?

23. What distortions can be removed from the information transfer process with regard to data compilation and cartographic design through to message interpretation?

24. What is there about spatial form that is possible to symbolize when showing data quality information?

25. What is a visual grammar? How does this contrast with other "types" of grammars. A grammar used to parse a natural language description of a scene? Can this be formalized? McGranaghan's herbarium descriptions, and public land survey descriptions might be examples.

26. Are image-schemas used in problems of visualizing scenes or locations given verbal descriptions? If so, do the schemas used differ because they are used to generate visual depictions of a scene, rather than to interpret scenes/maps?

27. If a "grammar" or "language" of graphics or images can be defined, then the techniques of cross-linguistic analysis should then be used to integrate the concepts of natural and visual language. (Arnheim's "Visual Thinking", and the discussion of it in Johnson's "The Body in the Mind" might be a good starting point.)

28. At the meeting, David Zubin presented a model involving four categories of spaces/ spatial objects. He did not propose names, but rather called them types A to D. (They became known as Zubin's "alphabet spaces" during the meeting.) Type A were everyday, manipulable objects; type B were larger concrete objects; type C included spaces that could be seen from one point, but by scanning; type D were spaces that could be experienced (sensed) only in small pieces. The question here is:

What categories of visual cues are necessary for interpreting each of these Types A-B-C-D spaces? Can cues be enumerated from specialist areas and used for interpreting the utility of "alphabet" spaces? How do we use visual cues to create relationships (such as figure-ground) between objects? What are the cues that are necessary to create relationships (e.g. shadowing in terrain simulation)?

29. Lang proposed 11 conceptual objects and relations which might be explored: point, line, and plane objects; line segments and directed line segments; axis (reference frame); boundary and regions; distance, direction, and dimension. Coordinate research on spatial language for small-scale spaces with work on large-scale (geographic) spaces.

30. What reference cues can be added to "impossible 3-D objects" (such as a classical optical illusion shown by Peuquet) to make them look like "realistic" landuse or other kinds of maps?

D NAVIGATION, WAY-FINDING, SPATIAL KNOWLEDGE ACQUISITION, SPATIAL INFERENCE

Spatial Knowledge Acquisition

31. Golledge has defined three kinds of spatial knowledge called Declarative Knowledge, Procedural Knowledge, and Configurational Knowledge. Compare Golledge's model of spatial knowledge to "other" spatial knowledge models in psychology, computer science, geography, etc. The purpose of this comparison is to define a model which is not limited to "geography applications".

32. Explore the acquisition of configurational knowledge from Golledge's other types of spatial knowledge. Freundschuh is currently exploring how the arrangement of the environment, length of time within the environment, and scale of the environment aids/hinders the acquisition of configurational knowledge.

33. Explore the use of "spatial stereotypes" to aid navigation for both blind and sighted navigators. Spatial stereotypes is a term used by Flury; an example is the use of the prototypical gridded American street (as well as sidewalk) pattern as a framework upon which directional cues are given. If one is able to rely on this prototype pattern, then is it possible that the pattern of routes can be pre-supposed, a "given" if you will. This idea has many implications for the blind. The research question is: "to what extent can spatial stereotypes be used in both blind and sighted navigation?"

Automated (computer generated) Directions

34. Data base issues: what information is required for the data base? Should a system select the shortest path, or the easiest path? How should one select cues salient to the route? This task would require a weighting or value for landmarks. A feature that is a salient landmark for one route may not be salient for another route, therefore, a value needs to be associated with features to determine their importance as landmarks for any given route. Two questions fall out of this: how can important landmarks be determined, and how should a weighting scheme for salient landmarks be designed?

35. There is a need to design algorithms for generating natural language navigation cues.

36. What is the "best" form of presentation of the navigation cues, i.e., visual (graphic or text) or auditory?

37. How can tactile maps for the blind be generated for places such as campuses? A constraint on these maps is that they contain updated information as to detours (both short and long term), areas undergoing construction, etc. (Golledge mentioned this during his talk)

Directions Generated by People

38. What constitutes "the best" or "the most appropriate" (i.e., good) directions? "Good" directions should:

    a) prime the traveler for the upcoming "choice point".
    b) give landmarks located at the choice point.
    c) give "too far" directions in case the choice point is missed
    d) give alternate directions when gone "too far" such as turn around or take an alternate route.

The aim of giving "good" directions is to 1) get the traveler from the origin to the destination, 2) reduce doubt on the part of the traveler; directions should be clear and unambiguous, and 3) reassure the traveler that they are on the correct route (need to determine at what point a traveler begins to need assurance).

39. The giver of directions needs a holistic view of the total route in order to: a) give complete directions from the origin to the destination. b) be informed as to what kind of landmarks can be confused, therefore, selecting (and explaining) appropriate cues. [Talmy referred to this as the cliff-face problem] c) give information on uncharacteristic changes or features in the route, such as forks where is may not be clear as to the actual route.

Variation in Directions

40. How do directions change with change in the size of the area being traveled across? i.e., as one gets closer to the destination, how does the information content of the directions change (more landmarks, more precise descriptions as to what the driver will see, etc.) We called this "fine tuning" of directions.

41. Are navigation cues different for navigation during the day compared with navigation at night?

42. How do directions vary for 1) walking, 2) mass transit, and 3) driving? Do directions vary for navigation within buildings compared with outside?

General Issues

43. How does a navigator deal with incorrect directions? What does one do when one gets lost?

44. Do directions change when given for a city (large scale) compared with when given for a town (smaller scale)? We raised the issue of names and landmarks that are recognizable only to the residents of the town, yet not recognizable to a stranger who happens upon the town.

45. How do directions change with the travelers familiarity of a place? Is greater care taken when giving directions to someone new to an area compared with someone who has lived there for 10 years? Are shortest routes given to long-time residents of an area compared with the easiest route for a newcomer?

46. How does terminology (language terms) change with scale of an area? i.e., do directions in a large scale space tend toward the use of "go north [south, east, west]" whereas directions in a smaller scale space tend toward the use of "go left", "go right"?

47. How do search procedures that do not terminate in a specific destination differ from those that do? Example: looking for hotels within a certain price range, therefore, indicating an area where one can expect to find such a hotel (but not a particular hotel).

E SPACE, SPACES, NATURAL-LANGUAGE ISSUES, AND LANGUAGE UNIVERSALS

48. What are universal constructs of space?

49. Identify formal "geometries" and "spaces" that underlie language and cognition.

50. Determine mappings (translations) among such spaces and also between them and the spaces used in GIS data models.

51. Determine when and where (for what problems, data types) should each space/geometry be used.

52. How do people use cognitive models in navigation (route selection, direction-giving, etc.)?

53. How do people explain spatial relations in natural language (in general)? (Specific examples include property descriptions, driving directions, biological localities, the "Swiss Army problem", etc.). Investigate the language used in a dialog between two persons which is conducted in order get the second person to focus on some particular point in a scene that the first person has selected. (This became known as the "Swiss Army Problem", because members of that Army are trained on how to do this systematically.)

54. How do these ideas relate to graphic communication?

55. To what extent can new approaches such as object-oriented programming, or neural nets, be used or combined to help deal with issues in spatial cognition that are not amenable to "conventional" programming?

56. Develop or obtain GIS market predictions by natural-language, to aid in prioritizing cross-linguistic work.

57. Investigate the spatial terms and constructions used by specialists in various fields, especially those of GIS users (e.g., forestry, military, marketing, etc.). How do experts' terms relate to the use of those terms in every-day language?

58. Conduct a cross-linguistic study of such systematized definitions that GIS users use.

59. Determine when languages use different structure-types for different purposes.

60. Compare the geographic uses of closed-class elements of natural language, open-class elements of NL, and mathematical primitives and relations.

61. Develop a discourse model for interaction with GIS. (The computer would keep track of the conceptual framework of a session, perhaps including previous sessions with that users.) A specific initial project might involve collecting scripts of GIS sessions, and then applying computer discourse analysis (perhaps using the CASSIE system at Buffalo) to study the interactions. Another approach would be to do the "reverse Turing" experiment, in which the GIS user interacts through a keyboard and mouse with a GIS expert, who gets clarification from users and then types the actual queries (a script would be kept, and analyzed using a CASSIE-like system). The long-term goal would be to build real-time discourse analysis into the user interface.

62. What is the space-concept (formal geometry) that underlies cognitive image-schemas?

63. What are the "invariants" of spatial language within one natural language, and can they define a "geometry", sensu Klein-Erlanger?

64. Closed class elements provide structure to a scene, and open class elements provide the content. It was proposed to conduct a graduated inventory of closed class elements related to space.

65. Investigate landscape generics. This would focus on elementary gestalts and image-schemas, and could be cast as an evaluation of USGS GNIS and DLG-E feature classes.

I-2 RESEARCH TO BE CONDUCTED AT THE NCGIA

As noted in the Introduction, this section describes specific Initiative 2 research and writing projects that are to at least begin at the NCGIA sites during 1989. Whereas we expect a few other projects to be initiated during this year, and yet a few more in 1990, the projects listed below nevertheless are expected to represent the bulk of the "deliverable" research to be conducted directly under NCGIA Initiative 2.

I: Multi-site Projects

1 . Auto Carto 9. Mark and Frank prepared a paper, "Concepts of space and spatial language", which was presented by Mark at the Ninth International Symposium on Computer-Assisted Cartography (Auto-Carto 9), Baltimore, Maryland, and published in the Proceedings of that meeting (pp. 538-556). The paper was also their "position paper", circulated to the participants in the I-2 Specialist Meeting before that meeting.

2. Bibliography of Spatial Languages and Related Topics. A bibliography is being compiled at Buffalo, and will be augmented with material collected at Maine and Santa Barbara, and published as an NCGIA Report.

3. Overview Paper for the Annals. We will write a paper which gives an overview of issues associated with Initiative 2, for submission to the *Annals* of the AAG. The co-authors will include Mark (Buffalo Geography), Frank (Maine Survey

Engineering), Couclelis (UCSB Geography), Zubin (Buffalo Linguistics), and perhaps others. The paper will present the conceptual framework for the I-2 research, a critical review of relevant literature, an overview of key issues, and (if possible) a summary of results. Note that the authors will include three disciplines and all three NCGIA sites.

4. NATO Advanced Study Institute. We intend to submit, by the July 15 1989 deadline, a proposal to NATO to conduct an Advanced Study Institute (ASI) on the topic: "Spatial Language, Spatial Cognition, and Geographic Information Systems". Mark would be the Director of the ASI, and Frank the co-Director. This would be of two weeks' duration, and be held in Europe just before or just after the *Fourth International Symposium on Spatial Data Handling* in Zurich, July 1990. The ASI would produce an edited book. Max Egenhofer (Maine post-doctoral fellow) is assisting with contacting European prospective lecturers.

5. National And International Conferences. We intend to organize at least one "Languages of Spatial Relations" session for the Association of American Geographers (AAG) Annual Meeting in Toronto, April 1990, and one or more sessions on the topic at the Fourth International Symposium on Spatial Data Handling in Zurich, July 1990. These sessions, together with the proposed NATO ASI mentioned under point 5, above, would constitute the "National or International Conference" that is held at the end of the formal period of each NCGIA Research Initiative.

II: Projects at Buffalo

1. Wayfinding, Driving Directions, Spatial Knowledge Acquisition. A t Buffalo during the summer of 1989, Mark and Scott Freundschuh (Buffalo doctoral candidate) will continue their research on informal driving directions. Twenty-one sets of directions have already been gathered, by having an investigator approach strangers in public places, ask for directions to some other public places (taping the response), and later transcribe them. Preliminary results were presented at the AAG in Baltimore, March 1989. Mark will continue to focus on gender differences in directions, and on the use of metaphor and metonymy (e.g., "get on Maple Road and it will *take* you there"). Freundschuh will concentrate on the kinds of things that are used as landmarks in driving directions; this will be related to Zubin's classification of objects presented at the I-2 specialist meeting. Additional directions will be taped and transcribed; some will involve a female 'interviewer', to try to control for possible interaction effects in gender differences already detected (with a male interviewer). This should lead to two papers, which will be submitted to refereed journals (to be determined).

2. Vehicle Navigation Aid Systems. Freundschuh, Michael Gould (Buffalo doctoral student), and Mark have each had individual papers tentatively accepted for the IEEE-sponsored *Vehicle Navigation and Information Systems '89* conference to be held in Toronto, Ontario, September 1989 (full papers will be screened before final acceptance). Writing of the papers during summer 1989 will be a fundamental Initiative 2 activity; vehicle navigation issues were mentioned is several of the "researchable questions" above.

3. Cross-Linguistic Analysis of Locative Expressions. At Buffalo during the summer of 1989, Mark and Gould will continue to study spatial prepositions and other spatial-relational and shape/extent terms in a cross-linguistic framework. The study will emphasize Spanish-English differences because: Latin America represents a major future market for GIS; Romance and Germanic languages have substantial differences in some aspects related to geographic space; Gould will be spending part of summer 1989 in Spain; and preliminary results will be presented in Venezuela. Gould will concentrate on Spanish, and will conduct field research in Spain this summer while there at his own expense. A paper on this work has been proposed to the Second Latin-American Conference on Geographic Information Systems, to be held in Merida, Venezuela, September 1989; that paper will be co-authored by Mark, Gould, and Joan Nunes, a Doctoral student from Universidad Autonoma de Barcelona (Spain) who studied at Buffalo between March and June 1989. A more complete version of the paper, incorporating results of Gould's summer research, will be submitted to the *International Journal of Geographical Information Systems*. Another paper, emphasizing cognitive aspects, and including results of Hsueh-cheng Chou's study of Mandarin, will be submitted to *Cognitive Science*. Gould also will tape some driving directions in Valencia Spain, to be compared to the English-language directions mentioned in the first Buffalo project, above.

4. Cross-Linguistic Study of Landscape Generics. At Buffalo during the summer of 1989, Zubin will conduct a cross-linguistic (German-English) study of landscape generics. This may be combined with a study of the feature codes in USGS digital cartographic data products, within the context of landscape generics and cognitive categories for geographic space (by Mark). Two publications (one for the linguistics literature, and one for the geo-cartographic) are planned.

5. Cognitive Aspects of GIS Interfaces. Michael Gould has organized a special session on user interfaces for GIS, for the GIS/LIS'89 meeting in Orlando, Florida, December 1989. The session will have papers by Gould; Jeanette Neal (Calspan-UB Foundation, Buffalo) and Stuart Shapiro (Buffalo CS, I-2 participant); and Mark, and will be chaired by , Matt McGranaghan

(University of Hawaii; I-2 participant). Cognitive and linguistic aspects of interfaces are emphasized, and the papers by Gould and Mark will be written under NCGIA support. It is intended that at least Gould's paper will be combined with a manuscript by McGranaghan and be submitted to a journal.

6. Augmenting the Geographic Capabilities of the CUBRICON interface. Neal and Shapiro are co-PIs of a DARPA-sponsored project to develop an "intelligent, multi-media interface". Their current project is a map-based system for support of Air Force mission planning. Currently, in answering the question "Where is XT', CUBRICON points to the referent on a map (with a flashing arrow); or redraws the map to include the object, and then points; or give the latitude and longitude. This summer, Susan Haller (doctoral student, Computer Science) will develop a conceptual framework and a prototype for providing natural-language answers to such questions. (For example: "Cleveland is in Ohio, on the south shore of Lake Erie.") This project will be informed by the cross-linguistic work being conducted under subproject 1, and should lead to publications, and to improvements in CUBRICON, and may become Haller's dissertation topic. Also this summer, we (Mark, Shapiro, Neal) will consider and develop a proposal for funding to further augment CUBRICON for GIS applications, and to link it to an actual GIS. Potential GISs for the project include KBGIS-II (developed by Terry Smith and others at UCSB), GRASS (produced by the US Army Construction Engineering Research Lab (CERL), QUILT, a quadtree-based system developed by Hanan Samet at Maryland, or perhaps System 9 (Prime Wild GIS Inc.).

III: Projects at Maine

1 . Formal Definitions of Topological Relationships I. In Egenhofer's recently-completed dissertation, an approach to define topological relationships has been proposed. This method is based upon fundamental principles of algebraic topology. During the summer of 1989, Robert Franzosa from the Department of Mathematics will assist Egenhofer in revising the mathematical section so that the theory can be published in a mathematical journal.

2. Formal Definitions of Topological Relationships II. In cooperation with John Herring (an I-2 participant from Intergraph Corporation), Egenhofer will investigate possible extensions of the theory described above. So far, the theory applies for n-dimensional objects in n-dimensional space. Investigations will focus on the extension to n-dimensional object in m-dimensional spaces (m>n). The results of this investigation will be published in the International Journal of GIS. Also, a joint paper for the 4th International Symposium on Spatial Data Handling in Zurich is planned.

3. Metrical Relationships. While metrical relationships between 0-dimensional objects in spaces of dimension > 0 are well-known, little investigation has been done on metrical relationships between I- and 2-dimensional extended objects. Metrical relationships are relationships which describe the distance or direction between two objects. It has been demonstrated that representations, such as the center of gravity, are inadequate for objects of concave shapes and are not appropriate for reasoning about metrical relationships. Frank and Egenhofer will study metrical relationships within a framework of 1-dimensional intervals. This framework can be applied both to distance relationships and---in a variation with cyclic intervals --- for direction relationships. The results will be published in two journal articles, the first one describing the theory and the conceptual framework; and the second article demonstrating how the theory may be applied to query languages and for reasoning about metrical relationships.

4. 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. Frank, Egenhofer, and Herring will investigate this conceptual framework. The first algebra has been defined with Egenhofer's theory of topological relationships. A second algebra will be defined for order relationships based upon recent the recent dissertation by Wolfgang Kainz. Some spatial relationships exist in both algebras, and we will investigate what the mappings between the two spaces are. Interim results will be presented in a paper at the 4th International Symposium on Spatial Data Handling at Zurich and a paper for the International Journal will report on the final findings.

5. Qualitative Reasoning about Space. Most current methods of spatial reasoning are quantitative, i.e., are based on measurable (metric) properties of space and the configuration of objects about which one reasons. For example, simple vector algebra allows for the deduction of distance and direction from A to C given the distance and direction from A to B and from B to C. More elaborate (quantitative) systems can deal with situations where the directions are expressed in different reference frames (e.g., in front of the home) or when the quantities are not exactly known. There have also been approaches to translate qualitative terms (near, far, south, etc) into fuzzy set quantities and then to calculate with them. Terry Smith (UCSB) and Frank will explore what power purely qualitative systems have. We will construct reasoning systems which are based upon distances (e.g., near, average, far) and direction (e.g., 4 or 8 cardinal points) and see that their power is. We expect to construct several of these and compare them

- what conclusions can follow
- what conclusions do not follow (e.g. assess their powers)
- where do they differ (i.e., which decisions differ between them).

We will also compare these qualitative spatial reasoning systems with the methods humans use. Of interest is to establish:

- situations where humans draw conclusions the formal system does not permit;
- situations where humans reach different conclusions.

We will publish an article, probably in the International Journal of GIS, or in a Geography journal.

6. Related Work: User Interface Design. Humans use different means to convey and perceive spatial information than they use for non-spatial information. Traditional it typed" query languages for user-machine interaction have been shown to be cumbersome in a spatial environment where much data is represented graphically. Jeff Jackson (Maine graduate student), Werner Kuhn (Maine postdoctoral fellow), and Egenhofer will investigate what appropriate techniques are to communicate with spatial data. These investigations will be based upon the methodology for user interface design developed in Egenhofer's dissertation and combined with the zoom and pan paradigm in the content domain. Jackson will write his master's thesis about this topic. Kuhn and Egenhofer will write a paper for a computer science conference (e.g. SIGCHI) and an article for the new URISA journal.

IV: Projects at Santa Barbara

1. Errors in verbal navigational directions. Helen Couclelis and Suchi Gopal are focusing on the different types of errors people sometimes make when giving verbal directions for navigation. These may be errors in the underlying spatial representation, errors in the route plan constructed on the basis of that representation, errors in the linguistic encoding of the 'cognitive plan', etc. The purpose of the research is to develop a model that would explain and reproduce such errors, thereby giving insights into possible cognitive mechanisms at the interface of spatial cognition, spatial reasoning, and language. David Mark's directions data base (see Buffalo project 1, above) is used at this stage, although a larger one will eventually be needed. The work of Couclelis on levels of spatial cognition will provide part of the theoretical background. Gopal had examined the issue of errors during route learning in the simulation model developed in her dissertation. The work is presently carried out with NCGIA support but there are plans for an extra-mural proposal.