LANGUAGES OF SPATIAL RELATIONS

January 15-19, 1989

Goleta and Montecito, California

Report compiled and edited by

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National Center for Geographic Information and Analysis

Report 89-2

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Preface and Acknowledgements

This is a report on a workshop entitled "Languages of Spatial Relations", held in Goleta and Montecito, California, January 15-19, 1989. The organizers wish to thank the management and staff of Casa di Maria (the conference site) for providing an excellent environment for the meeting, and Sandy Glendenning, Phil Parent, and others at the NCGIA head office at UC Santa Barbara for assistance before and during the meeting itself.

The first draft of this Report was prepared by the raporteurs of the meeting, namely (in alphabetical order) Max Egenhofer, Scott Freundschuh, Matt McGranaghan, and Mike White. Then, David Mark reviewed each section in light of his notes, and added any appropriate material. Thirdly, each section was sent to some third person for further additions and amendments. Michael D. Gould did most of the illustrations. This report was assembled, edited, and distributed in draft form to all of the participants in the Specialist Meeting, who were given about a month to provide corrections, additions, or suggested revisions. Helen Couclelis provided detailed editorial comments on an earlier draft of this report; several other participants also provided useful feedback.

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.

EXECUTIVE SUMMARY

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 reported on in this document 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.

This report is primarily in the form of a transcript of the meeting, reporting what was said, and focussing on discussions and debates. The first day of the meeting introduced the participants to each other and to some basic principles of cognitive linguistics. This was followed by two days of short presentations and intensive discussions on a variety of aspects of the topic. The fourth and final day involved break-out into working groups-- two in the morning and four in the afternoon-- to identify and prioritize researchable questions related to this Research Initiative. Appended to this report are three essays submitted after the meeting by participants. A list of participants also is included.

INTRODUCTION

The National Center for Geographic Information and Analysis was established by the National Science Foundation in 1988, with a mission to conduct basic and applied research involving computer handling and analysis of geographic information, to educate professionals in this area, and to disseminate findings and transfer technology. Research at the NCGIA attempts to remove conceptual and technical impediments to progress in the use and analysis of geographic information. Research is conducted primarily through *Research Initiatives*, which run for 12-24 months, and which provide focussed efforts on a limited number of carefully selected topics. Initiatives will run for 1-2 years. Each Research Initiative involves more than one institution, and covers more than one discipline. The sequence of Initiatives has been selected so the results of early initiatives can be used as a basis for later ones. Research Initiatives begin with *Specialist Meetings*, intensive 2-5 day workshops that attempt to identify and prioritize a detailed research agenda for a topic.

This report presents the content, and some results, of the NCGIA Specialist Meeting for Research Initiative 2, "Languages of Spatial Relations". 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. GISs of the future may be used more and more often in moving vehicles and other situations in which output in the form of synthesized speech may be more effective than output in the form of maps. Cognitive science provides a framework for relating geographic language, and spatial relations and concepts, to GIS data structures and queries.

In an attempt to define an agenda for overcoming some of these impediments, a meeting was held in Santa Barbara, California, during January 1989. This meeting brought together geographers, cognitive linguists, engineers, computer scientists, and others (see participants list in Appendix B). The great majority of this report is, in a sense, a synthesized transcript of what was said during that meeting. It is written in chronological order, primarily in the hope someone reading this report will get a good idea about what it was like to have been at the meeting. A draft report was prepared from notes taken during the meeting, and then augmented from the notes of others, or from comments and corrections provided by the participants. To keep the transcript style, comments that participants "wished they had made", but did not, have not been added to the main text. Some post-meeting comments from some participants are included in this report as Appendix A.

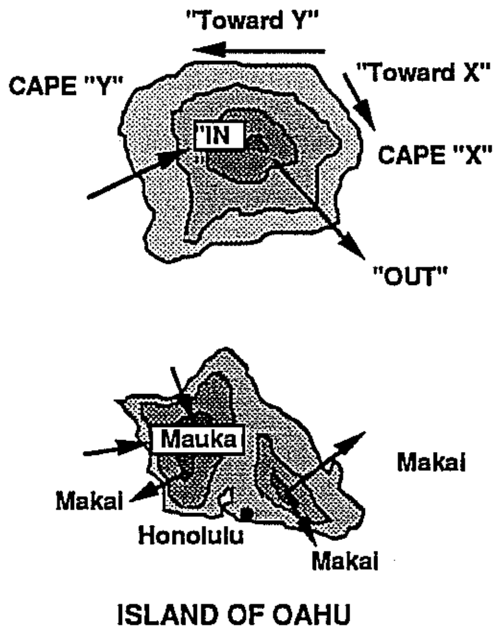

Figure 1: Current GISs use cartesian coordinate systems. Many peoples and natural languages use radial reference frames. Unwary translation of directional terms could lead to incorrect map labeling, spatial descriptions, or spatial inference.

REPORTS ON THE SESSIONS

SUNDAY MORNING

Opening and Introduction

David Mark welcomed the participants on behalf of the co-leaders of Research Initiative 2 of the NCGIA, and gave a brief outline of this workshop. Terry Smith welcomed the participants on behalf of the Santa Barbara site of NCGIA.

Andrew Frank then introduced the NCGIA and its structure, a consortium of the University of California at Santa Barbara, the State University of New York at Buffalo, and the University of Maine. The consortium is led by the co-directors David Simonett (UCSB) and Michael Goodchild (UCSB), and has three associate directors, one at each site (Terry Smith at UCSB, Ross MacKinnon at SUNY Buffalo, and Andrew Frank at Maine). Among the goals of the NCGIA are to bring computational ideas inherent Geographic Information Systems (GIS) into the world of geography and related disciplines, and to remove current impediments to the use of GIS and geographical analysis in basic and applied research. Three important issues are defined: (1) multi-disciplinary research on a few selected topics; (2) development of guidelines for introductory courses in a GIS curriculum (education); and (3) cooperation with industry, through workshops, etc. (outreach).

Several points were made regarding the basic purposes of NCGIA. One was the exploration of fundamental theoretical issues, which could be put to use and developed into better GIS tools. The joint roles of research, education, and outreach at the NCGIA were stressed, as was the rationale for targeting research topics which could be usefully attacked in the next two years. Mark commented that the "analysis" in NCGIA indicates a need to go beyond simply building better information systems.

Mark introduced the structure of the current initiative (I-2). A general theory of spatial relations will involve several things. One is human cognition of space and the natural language that is used to represent spatial relations. Another part is the computation involved in a mathematics of spatial relations. Between these is the bridge offered by a "geometry of language". Prior to this meeting, there was a meeting at Buffalo in June 1988 on spatial languages, subsequently referred to as the "June Meeting". Several of the current participants were there too. A report on that meeting was compiled and edited by Mark, and published as NCGIA Report 88-6.

Disciplines and perspectives represented in the current meeting are geography, cognitive linguistics, mathematics (for the treatment of geometry), human navigation, spatial behavior, and naive physics. Mark stressed that no paper sessions were planned for this Specialist Meeting, the objective being the discussion of issues. Mark cited Peuquet for noting the need to develop a "theory of spatial relations" and how it relates to database structures. He identified two components of spatial relations: (1) the cognitive side (conceptualization of theories), and (2) the formal side (implementation of the theories). As a motivation he presented examples for three different interpretations of "East". We also discussed some geographic reference frames, including cardinal directions (north, south, east, west), radial reference frames (such as are used in Hawaii; see Figure 1), and general models of frames.

Mark presented Freeman's 13 spatial relations which Freeman claimed to be a complete set. Herring commented that 12 were binary relations, while BETWEEN was a relation involving 3 objects. Egenhofer questioned the completeness of this set because an EQUAL relation was missing. The participants agreed that Freeman's set was not complete.

Mark distinguished theoretical and practical issues. Theoretical issues were: how do people think about geographic space; the influence of cognitive models of geographic space upon decision making and behavior; and understanding of spatial aspects in narrative text. Practical issues are user interfaces, e.g., natural language, selection of best words in menus; design and structure of possible queries; and fundamental database design.

The understanding of spatial languages has two cores: (1) spatial relations in natural language; and (2) mathematical representation of spatial relations. These two cores lie within the general framework of Concepts of Space and Spatial Relations, and Geometry of Language can function as a bridge between the two cores. David Mark organized around this framework Spatial Behavior, Naive Physics, Human Navigation, Linguistics, and Geometry. This observation was the outcome of the June meeting.

Frank presented the program and the outline of this meeting. Participants were invited to provide a 2 to 10 page paper for inclusion in the final report. (Papers received are included in Appendix A of this report.) Because we were trying to avoid "paper sessions", the program that was distributed was to be considered to be a reference, and not a strict schedule.

Self-Introductions of Participants

These remarks were followed by the self-introduction of the participants, including current research interests, especially in relation to the topic of this meeting; participants are listed in clockwise order around the table:

David Mark (Geography, SUNY/Buffalo) mentioned a particular interest in driving directions, in addition to more general concerns;

Max Egenhofer (Surveying Engineering, Maine) stated interests in object-oriented software engineering and database management systems, formalisms for spatial relationships, and spatial query languages;

Andreas Flury (Geography, UCSB) expressed particular interest in navigation assistance;

John Herring (Intergraph) stated particular interest in formal query languages for GIS, formalisms for spatial relationships, and other topics mentioned by Egenhofer;

Stuart Shapiro (Computer Science, SUNY/Buffalo) conducts research in artificial intelligence, the modeling of intelligent, language-using entities in computers, deictic centers, spatial reasoning, reference frames, natural language understanding, and intelligent, multi-user interfaces;

Roula Svorou (Linguistics, Ph.D. from SUNY/Buffalo) studies the expression of spatial relations in natural language, primarily from a cross-linguistic perspective;

Robin Fegeas (USGS) has interests in user concerns, next-generation GIS, standards, and terminology;

Terry Smith (CS/Geography, UCSB) is concerned with formal languages for spatial data that support inference; "language as data compression" also was mentioned;

Helen Couclelis (Geography, UCSB) noted her background in architecture, planning, and geography, and her interest in kinds of spaces, and in natural language as a gateway to spatial thinking;

Reg Golledge (Geography, UCSB) examines spatial decision-making, choice, spatial behavior, and especially studies special populations, to try to see how spatial information is acquired, encoded, and used.

David Embley (CS, Brigham Young) examines database systems, software engineering, and semantic model query languages;

Michael White (Surveying Engineering, Maine) studies constraint-based systems for geographic modeling, LIS, and deed descriptions;

David Zubin (Linguistics, Buffalo) focuses on cognitive semantics and discourse representation.

Len Talmy (Cognitive Science, UC Berkeley) studies how language organizes conceptual material, and how that relates to perception, especially for space and time, motion and location, viewpoint and distribution of attention, interaction and force dynamics; language of space and time resembles early science, naive science, casual science;

Scott Freundschuh (Geography, SUNY/Buffalo) examines knowledge for navigation, and the influence of regularity of space on learning;

Suchi Gopal (Geography, UCSB) develops computational models of spatial navigation, and errors in the use of heuristics;

Jan Van Roessel (USGS EROS Data Center) conducts research on query languages, models for spatial objects, abstract mathematical models of spatial objects and relations, especially with respect to standards;

Steve Smyth (Spatial Data Research, Inc.) is involved in building modeling systems that are experts in particular areas, and in integrating them to deal with aspects of the real and perceived world; he also participates in an ANSI subcommittee on SQL extensions;

Mark Ashworth (Wild) is involved in GIS R&D, including object-oriented programming, spatial extensions to SQL, and user interfaces;

Ewald Lang (Linguistics, Wuppertal) studies cognitive language, especially for dimensional terms, locative prepositions, object-schemata, Gestalt principles;

Matt McGranaghan (Geography, Hawaii) examines cartographic perception, spatial cognition, and in particular textual description of biological localities;

Donna Peuquet (Geography, Penn State) has current research interests in spatial knowledge representations and cognitive/geometric models of spatial relations, particularly the investigation of an integrated framework of spatial representations and relationships;

Tim Nyerges (Geography, Washington) has focused on spatial cognition, and more recently in cartography and GIS, especially conceptual models of spatial cognition, and a search for a framework for integrating categories of spatial objects, map knowledge, expert systems, and translations among models;

Bruce Palmer (Digital Equipment) is concerned with spatial analysis systems, spatial theory, visual thinking, and the need to incorporate human minds into system design;

Andrew Frank (Surveying Engineering, Maine) is interested in many of the above topics.

(Participants who were not present at this opening session included Armando Guevara of ESRI, and Michael Goodchild, John Loomis, Waldo Tobler, and David Simonett of UCSB.)

At this point, the meeting adjourned for lunch.

SUNDAY AFTERNOON

Session 1: Len Talmy on "How Language Structures Space"

Len Talmy discussed how language structures space. (For details, see Talmy, L.,1983, "How language structures space", in H.Pick and L. Acredolo, editors, *Spatial Orientation: Theory, Research and Application.* Plenum Press.) Talmy's basic thesis is that the fundamental categories and parameters that we use in communicating about space structure our concepts about it.

Talmy advanced the notion of there being three "imaging systems" in language for structuring space. These are: schematic structure (pieces and relations), viewpoint, and distribution of attention. Changes in them through time are also important.

This structuring of space is performed primarily by closed-class grammatical elements, of which prepositions are a good example. (Closed class elements for English also include conjunctions, articles, inflections, etc.) English is very rich in closed-class elements; they often carry information about tense and plurality. Closed-class elements tell the listener what is important in structuring concepts. Open-class (lexical) elements (such as nouns, verbs, and adjectives) convey the majority of content.

Embley: What about "correct" and "incorrect" usage, such as when someone uses between when referring to more than two reference objects?

Talmy: There is no such thing as "correct" usage [in cognitive linguistics]; there is only what people say and what they do not. [Things that native speakers of a language never would say are, in linguistics notation, preceded by an asterisk (*).]

Image Schemas
Talmy discussed the schematic structure in which prepositions may specify location, as e.g. NEAR some object (which might be treated as a point, although it might be a line or an area). Prepositions BETWEEN, AMONG, and AMIDST specify location with respect to more objects. Terms and relations are not mutually exclusive, not collectively exhaustive. They often have a representative distribution, plus distorted use and compounded use.

Motions can also be conveyed by prepositions, e.g. ACROSS, which refers to motion between the closer (to each other), longer sides of an arealy-extended object. "I walked across the pier" would mean from one "side" to the other, perpendicular to its long axis. English, it seems, has no preposition for walking the length of something, and so must use more extended phrases ("I walked the length of the pier.", see figure 2)

Take the example: "The snail crawled across the car." Understanding this utterance requires "schema-juggling". We have a car schema, and an across schema, and must combine them to interpret the probable motion of the snail. Golledge suggested that the long and short axes are important.

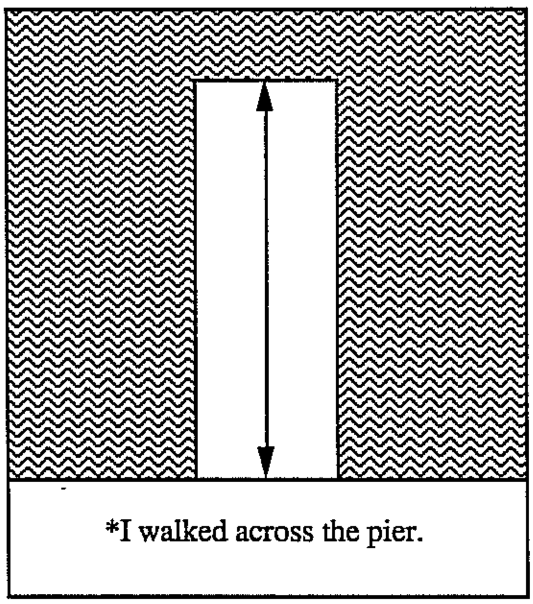

Figure 2: In English, on cannot say "I walked across the pier" when the crossing is parallel to the long axis of the pier.

Across also suggests linear motion "across" the visual field. In "the caravan moved across the desert", the caravan does not have to travel from one "side" of the desert to the other, and in fact the desert does not need to have "sides" at all. Thus, although "he walked across the room" may require completion, reaching the other side, this is not required for the car and snail example. Is there a single basic meaning, or already multiple meanings?

Talmy drew a picture to represent the uses of a word in an abstract property space (see Figure 3).

The region may contain "clumps" of well-defined common meanings, but also some "common denominator" of shared conditions. Both "mis-represent" the "meaning" of a term. Both can be included in the radial categories discussed by Lakoff and others.

Fegeas: The importance of location and motion are not clear. "The road goes into the mountains."

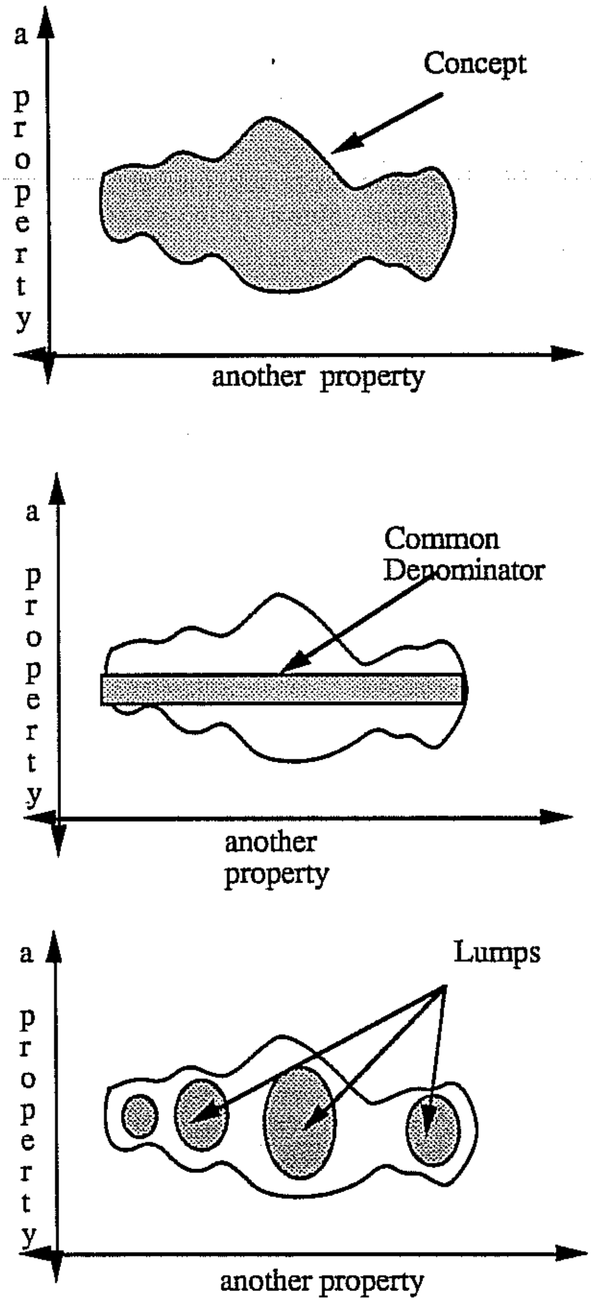

Figure 3: Both the "common denominator" and the "clumps" generalizations misrepresent the category, but radial categories (Lakoff) can handle this kind of situation.

Spatial Properties and Nouns

Nouns convey several parameters: boundedness (bounded / unbounded), plexity (uniplex / multiplex) and dividedness (discrete / continuous). For example, "water" is unbounded. Words, like SOME, indicate boundedness, or may be thought of converting an unbounded thing into a bounded one. All languages allow ways to signal these parameters, usually making it easy to keep the central idea, but modifying a parameter. If one only has a lexical uniplex element, then a terminal "s" in English multiplexes it. There are some special cases in English. For example, one can shift the plexity of "shrub" by adding "-bery" to produce "shrubbery", signalling multiplexity rather than uniplexity. Yiddish makes it easy to perform unit extraction, whereas English has to add another word to extract a unit (eg., a blade of grass). "A drop of ____" is used to indicate a particular size-range and shape for any liquid, whereas "tear" connotes size, shape, material, and origin.

Frank: Are boundedness, plexity, and dividedness necessary and sufficient, or do some languages have other similar concepts, or omit one or more of these three?

Talmy: We could develop an ordered list of language properties, ranked by the proportion of languages that have them. At the top of such a list, all languages have predication. Most indicate the plural through a suffix, whereas only a very few (but some) have time-of-day as an ending. Boundedness is very high on a frequency ranking of concepts represented across languages.

Imaging Systems

Talmy also discussed topological imaging systems. Four important points of the linguistic-topological structuring of space were enumerated. These concepts are: (1) magnitude-neutrality ("across" applies to hands, tables, and continents); (2) shape-neutrality ("across" applies to circular pies and rectangular cakes); (3) linguistic and mathematical topology are not the same. Linguistic topology is more abstract in that it is closure neutral and continuity neutral. It is also less abstract in that it is sensitive to magnitude under global assessment. The examples discussed were David Mark's "*My barbecue is near San Francisco" and the idea that "swimming across a lake" seems to require that the path of swimming divide the lake into two (approximately equal) halves.

Zubin disagreed slightly with Talmy's idea of magnitude neutrality, claiming that large-scale space and small-scale space had an effect on magnitude; i.e., wagon on a prairie is unbounded, but a microbe on a palm is not unbounded. Talmy responded by stating that with the examples given by Zubin, the relative sizes between the objects are still magnitude neutral.

Talmy stated that there is no known spatial preposition that is size sensitive; Svorou observed that Karok has two verbal suffixes for "going down", one from the height of a man and the other from higher objects (eg., a cliff). Talmy suggests that such cases often turn out to be defined by something else, that there is probably a qualitative element which is manifested in a quantitative distinction.

Svorou suggested that dimensional (and color) adjectives are "almost closed" classes. However, whereas there is no known cases of a new preposition coined as part of a technical lexicon, these occasionally occur for the adjective classes suggested by Svorou. Zubin noted that closed-class elements evoke more abstract aspect of the ground object.

It was suggested that "*My barbecue is near San Francisco" is problematical because of incompatible sizes of the objects involved. But Mark suggested that "The meteorite fell near San Francisco" is perfectly all right, even if the meteorite is no larger than the barbecue.

Golledge brought up the subject that geographers have long tried to distinguish between shape and pattern. It is partially a problem with language. English is not good for pattern, and sometimes we use the language of shape to describe pattern, even though pattern and shape are not the same concept. Golledge's example: "A hexagonal pattern of points."

Talmy noted that this problem applies to architectural drawings as well.

Shapiro: Isn't this phenomenon just standard productive metaphor? When we don't have language to explain new phenomena,we use metaphors which are not "quite right", but are adopted for lack of "correct" terminology.

Talmy: But, we are "built" to use a particular cognitive structure.

McGranaghan: We have some words or noun-phrases for particular shapes, such as "atoll" or "dissected cone". Mike Peterson's dissertation (completed at Buffalo in 1981) discussed the role of pattern in perception and memory of maps.

Golledge: Natural language doesn't have a way to really deal with pattern.

Herring: The star patterns known as constellations were named to aid memory, because star patterns were so important. Patterns were not as important for other kinds of things.

Frank: Heraldry has specific terms for pattern and shape.

Golledge: For geography, we can hardly go beyond uniform, clustered, random.

Nyerges: Isn't it true that pattern is much more complex, and that's why we don't represent it directly in language?

Homologies Between Spatial and Temporal Language

Talmy moved to a discussion of the homology of temporal and spatial structuring. In both domains we may describe things occurring once at a place (or time), occurring repeatedly in a bounded region of space or time, extending to a bound in time or space, or extending from one point to another.

The Viewpoint from which space is described is also encoded in language. A global, steady-state, long-range viewpoint is marked by: "there are a number of houses in the valley." In contradistinction, "there is a house every now and then through the valley", shifts the viewpoint to a close-range and gives it a local, sequential scope of attention.

The distribution of attention is also conveyed by language. This ascribes figure and ground status to elements within a scene. Primary attention is allocated to the figure while secondary attention goes to the ground. Talmy identified several properties which characterize ground objects and figure objects.

The scope of attention is also specified linguistically. Driving a car through terrain can be described from: (1) a global frame (observing both the terrain and car as from a distance); (2) a local frame (where the viewpoint is shifted to the car and the terrain is said to move past it); (3) as changing through time. But there are: (4) constraints on where the viewpoint can be placed.

Golledge presented an example: "The rock formation appears (or occurs) at several places in the county".

Talmy noted that one can mix events with locations where the events occur. A rock outcrop can be seen as a event.

There was a brief discussion of the statement: "He drove the bus across the United States." This would not normally be used for a trip from the Canadian border to the Mexican border, but rather strongly implies an east-west trip. This seems to make sense only in a north=up frame. Are there descriptions of trips across Europe in the dark ages, when east was positioned at the top of maps? Did they use "across" for north-south trips?

MONDAY MORNING

Session 2: Natural Language Understanding and Reference Frames

Ewald Lang

Lang discussed two interacting sets of principles by which spatial objects can be defined. The first is Inherent Proportion Schema (IPS), and the second is Primary Perceptual Space (PPS). IPS defines the dimensionable gestalt properties (inherent gestalt properties) of a spatial object, and PPS defines a system of axes within which the gestalt properties of objects can be interpreted as position properties (properties induced by the context).

Lang presented a model of PPS (see Figure 4) which he stated is a model of how external physical space is conceptually reconstructed in terms of categorized sensory input from our senses. While IPS is based primarily on vision, PPS draws on other "perceptual input available from the organ of equilibrium, from upright walking, and from eye level". Each of these contributes a set of principles which define three distinct axes which, in turn, define our internal model of the external space. The three axes are:

1. Vertical Axis: this axis is defined by gravitational attraction (i.e., equilibrium). This axis is constant and ubiquitous (gives rise to up-down), therefore, is superior to the other axes.

2. Observer Axis: this axis is due to sight, has an anatomically determined pivot allowing for a 180 degree turn. This axis is orthogonal to the vertical axis (gives rise to front-back), and the directions is determined by the direction of the eyes.

3. Horizontal Axis: this axis cannot be identified by primary perceptual information (gives rise to left-right). It is the least salient of the three axes, and we have no biological mechanism for sensing it. It fills the gap that remains due to the nature of the other two axes.

Lang stated that some objects do have their own "object axis" which is projected onto the axis of the primary perceptual space. Objects with inherent object axes have their own perceptual space encoded in them in a constant manner. An example of this is a book. The height of a book is constant, and it is always understood what dimension is being referred to when indicating the height of a book, regardless of of the book's orientation.

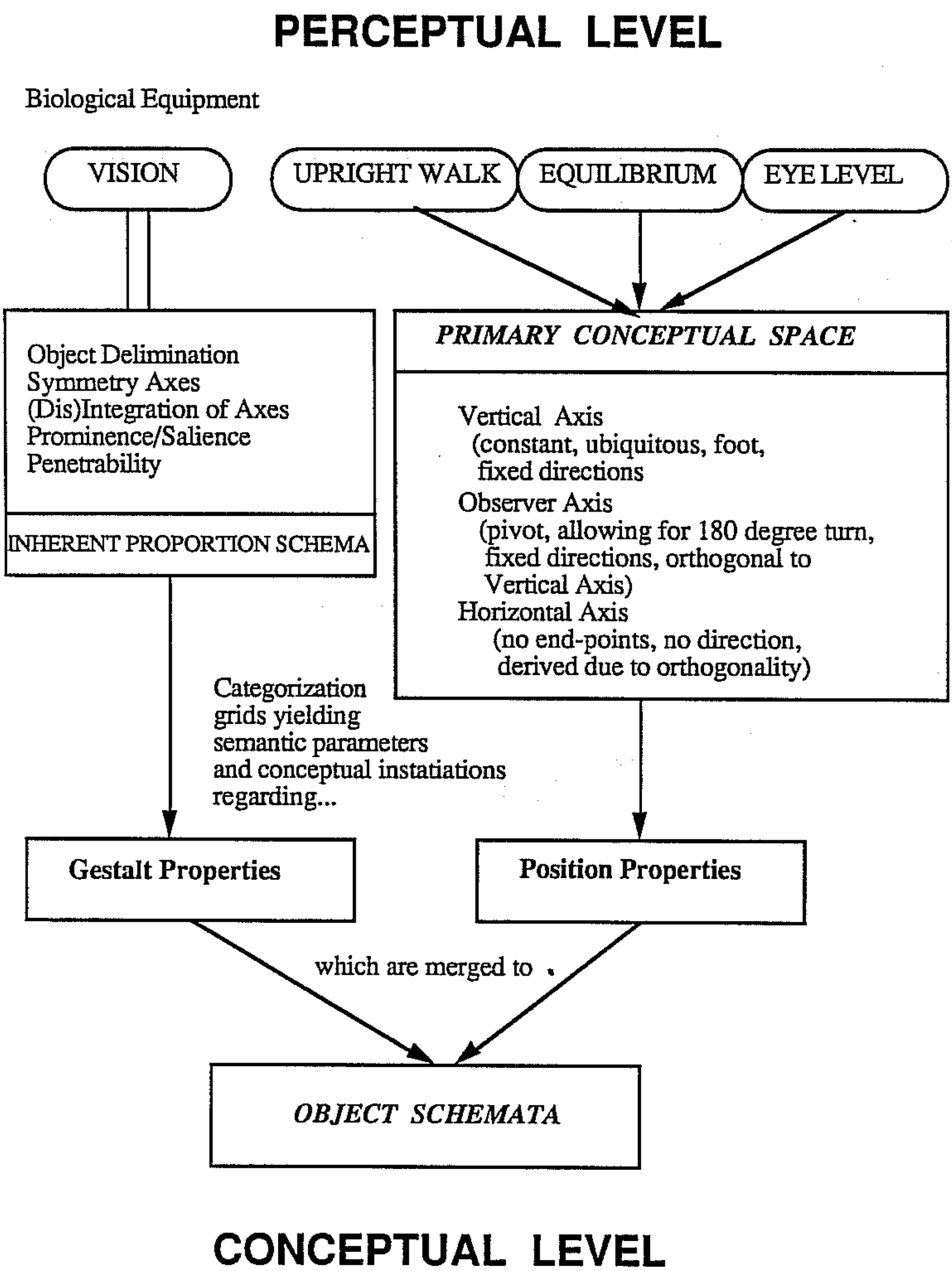

Figure 4: Lang's model of inherent (Gestalt) and cannonical reference frames for assigning terms to the dimensions of an object.

Similarly, the use of "high" in the sentence:

The pole is 3 meters high

also invokes a gestalt reference frame, although in this case the major axis is typically vertical; conversely,

?The tower is 3 meters long

is unusual, if not invalid, because a tower has a canonical vertical orientation, so that its maximum extent is normally referred to as its height even if it happens to be lying horizontally. Another example was a hole which has depth, regardless of its orientation. Objects which lack their own inherent axes are tied into perceptual axes of the observer.

Lang also pointed out that some properties, such as "height" are "inheritable; the "height" of a brick refers not to inherent properties of the brick, but to its extent in the direction of the "height" of a wall of which it is part.

Talmy asked for clarification on this point. He seemed satisfied that length is tied to the maximal dimension of an object, while height is based on vertical extent.

Lang commented briefly on the exchange between Frank and Zubin at the June 1988 workshop, as recounted in the report on that meeting (NCGIA Report 88-6). Frank was reported to have stated: "Our perception organizes the space", to which Zubin replied: "Our perception *constitutes* the space." Lang elaborated: "Perception constitutes the space to the extent to which the space is organized by conceptualizations. And conceptualizations mean interpreting perceptual input with respect to its behavior."

Golledge pointed out that Lang's schema deals with single objects, but geographers deal with groups of objects, or many objects. Golledge then asked, "How does Lang's schema deal with several objects?" Lang's reply was that his schema allows us to classify objects into groups which can then be treated as objects. Golledge then raised the issue of how can we deal with spatial distributions using this schema? Talmy commented that this was an important question; how can we deal with a group of lakes, or a group of houses? Zubin commented that to discover how we deal with groups of objects is to identify how the "normal" person locates houses (as an example) and try to determine how natural language structures these descriptors. A paper by Steven Palmer, in Rosch (editor) "Categories and Cognition" was mentioned.

Tobler raised the question of "How does Lang's schema deal with objects that change shape, such as clouds, amoebas, flocks of birds? David Mark noted that motion gives an axis to such objects. Lang replied that his schema deals with bounded objects and that flocks of birds, clouds, etc. are not bounded objects. Talmy suggested that both the axis imposed by motion and the position of the object relative to the observer would be important in establishing reference axes about an object. It was noted that time is not included in Lang's schemata.

David Zubin

Zubin began his presentation by posing the the question "what scale of space do we deal with when we are trying to describe objects?" He and Lang had traditionally dealt with small-scale objects, but when he extended his model to large-scale objects, things were not as well controlled. He then presented a diagram linking all the conceptual aspects that

Initiative 2 is concerned with to the topic of Theory of Spatial Representation (see Figure 5). He discussed (1) Formal/logical Systems of Spatial Relations, (2) Studies of Language Structure, (3) Human Cognitive Representation, (4) AI Models of Spatial Knowledge, (5) Psychology of everyday experience, and (6) Culture-Specific Aspects of Spatial Languages (see diagram below). Cross-linguistic studies are especially valuable because, when we study one language, we often come up with "cognitive" principles that are properties of the language studied, rather than of cognition in general. Don Norman's work on the psychology of everyday experience, and the related area of naive physics, also are important sources for this. Each of these approaches may differ in the way they conceptualize space and Zubin pointed out that we will not come out with one view of space which is all encompassing.

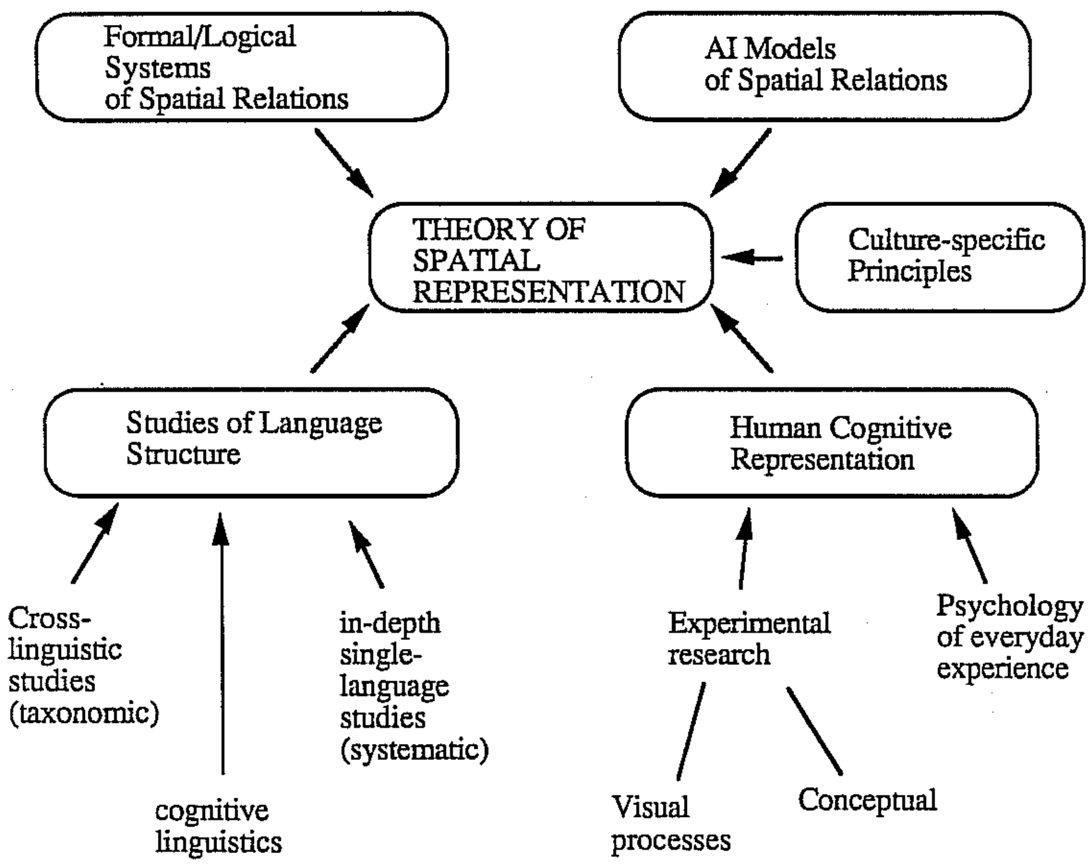

Figure 5. David Zubin's model of research topics in the area of "Languages of Spatial Relations"

Zubin then presented a model for scale differentiation of spatially distributed percepts that people deal with in everyday life. This model consists of 4 types of objects, which are as follows:

Type A objects:
- are less than or equal to human size
- are contained in a static visual field

- are manipulable by human beings, or at least are highly movable; they are "omni-perspectival" (that is, they can be freely rotated, both as physical objects and/or by "mental rotation")

Examples are: a pen, plants, animals, hand-sized artifacts, parts of larger objects.

Type B objects:
- are greater than human size
- one perspective in the visual field
- are not manipulable
- much less movable, or prototypically do not move at all
- are mono- or poly-perspectival (seen from few views)

Examples are: the outside of a house, an elephant, trees, large machines, a fence, a mountain, a pond in the woods.

Type C objects (scenes):
- can be perceived only by scanning
- a constructed perspective

Examples are: this room [large], a yard, a field, a lake, a small valley, a theater (inside), a cave. Steve Smyth asked whether the horizon was an example. Zubin said, "Yes."

Type D objects (territories):
- cannot be perceived as a unit
- small portions are perceived as Types A and C objects
- there is no perspective

Examples are: A forest, a desert, a town or city, a farm, a state, a country, an island, a sea, ocean, the inside of a house or an apartment, the shoreline of a river.

Zubin then discussed how we can shift the scale (view point) of everyday objects in experience, and that an object can be a Type A object at one scale, but a Type B object at another scale (see diagram below). In figure-ground relations, Zubin suggested that the scale type of the ground should be greater than or equal to the scale type of the figure; for example, to locate a scene, the ground must be another (larger) scene or a territory. Also, knowledge of types A and B objects tends to be declarative (in the sense used by Golledge), whereas in the cases of type C and especially type D objects, knowledge tends to be more procedural.

There was a short discussion on the term "across", and its relation to the "Type" of objects. When dealing with Type A and B objects, "across" relates to the boundaries of the object, such as across the pool or across a palm. In contrast to this, when dealing with Type C and D objects, "across" refers to or indicates a portion of the object; the boundary is not important. Examples of this are across the desert, or across the prairie. The scale of the object seems to be responsible for indicating boundaries of the object (Types A and B) or for indicating only a portion of the object (Types C and D).

Talmy stated that some large scale objects (Types C and D), once they are conceptualized, can be considered or thought of as Type A and B objects. Zubin agreed, and stated that this change in object Type is related to the shift in scale (view point), and how object Types can shift depending on the scale shift.

Zubin also noted that the relation between shape and dimensional terms may be size-dependent. For example, a fish hook (Type A) does not normally have a "length"; if it does, the term would not refer to the total distance from one end to the other, measured along the curve. However, for a curved road through the mountains (Type D), the "length" exists and clearly refers to the total curvilinear extent measured along the road.

Embley noted that query languages are either procedural or non-procedural, and suggested that non-procedural methods work best for small (Type A) objects, but may break down for larger objects.

These types of objects seemed to lie along continua that looked something like this (see Figure 6):

TYPE

	A	B	C	D
Measure	dimensions& gestalt			distance metric
Boundaries	sharp/intrinsic			vague/extrinsic
Location	figure			ground
Navigation	landmarks			domains
Reference frame				
inheritance		?		
origin	ego			environment
description	declarative			procedural
Lexical taxonomy	spatial			?
containment		?		

Figure 6: Some properties of objects in Zubin's taxonomy of spatial objects and spaces.

Talmy noted that the way in which individuals interact with an object may be more important than size alone. They may "chunk" pieces of the large scale space. Zubin noted that we can "convert" objects from one Type to another. Talmy responded that there is no need to talk about this as a scale effect. Both Robin Fegeas and Tim Nyerges commented on, and clarified, the fact that cartographers use the terms "small scale" and "large scale" in ways that appear to conflict with the way they are used in this discussion. A "small scale" map portrays regions of relatively large extent, and "large scale" maps portray smaller objects. If the size of the display medium (paper or CRT) is held constant, then as map scale (ratio of mapped size to real-world size) is increased, the size of the largest object that can be shown decreases.

McGranaghan stated that the eye normally performs a series of foveal fixations, no matter what size the object is. How does the model distinguish foveal from non-foveal vision? He questioned how Zubin's model accounts for these fixations. Zubin replied that it may be a matter of the degree of scanning required, and of the moveability of the object.

Stuart Shapiro

Shapiro discussed reference frame understanding, and the selection of the correct reference frame when there are conflicting reference frames. He used an example of computer generated output to demonstrate work that he and Han-yong Yuhan (one of his former graduate students) completed. This work involved the development of an algorithm that could "read" text, and then "say" what it "understood" via printed output. Shapiro stated that to test this algorithm, text containing situations in which there were conflicting reference frames was given to the computer, and the corresponding output was analyzed. Overall, the program was successful in understanding reference frames in the example text, though it did have minor problems with distinguishing the difference between moving "down an aisle" and moving "down vertically". Resolving conflicts between reference frames is an important part of the future development of such a system. In natural language, reference frame shifting is often complex but people usually follow these shifts.

Session 3: Geometry Defined by Invariants

Andrew Frank

Frank began this session with some very brief observations concerning what had been presented in previous sessions. He observed links between Talmy's invariants (such as IN), and geometry, though he did not say what he though those links were. Frank also stated that he thought that links exist between Zubin's Type A, B, C, and D objects. Frank discussed concepts of "geometry". In the early 19th century, the fact that the axiom of parallelism from Euclidean geometry could not be proved led to redefinition. Felix Klein presented the idea of "a space" and properties that remain invariant under "a group of transformations." Frank raised the questions "what properties of language remain invariant?", and "do Type A, B, C, and D objects have different geometries?" There was no response to these questions.

Roula Svorou

Svorou discussed some invariant properties of terms of containment. She began by defining terms that described containment. A geometric definition of containment is "inclusion of a geometric construct in a one-, two-, or three-dimensional geometric construct." A functional definition of containment is "trajectory (FE) contained in landmark (GE)". There seems to be a tendency to use procedural words for larger scales, and extensional words for "Type A" objects. She then explained the two types of situations that containment terms describe:

1. Closed containers such as a box, a car, a phone booth, and a wallet.

2. Open containers such as a basket, a boat, cupped hands, and a hole.

Some languages make distinctions between these. All languages seem to have at least one term which makes no distinction between these types of containment. Some distinguish whether a closed container has its lid on or off.

Svorou then gave numerous examples of containment in several languages such as English, French, Papago, Navajo, and Atsugewe. Palmer then asked what the distinction was between movement into a gravitic container and vertical movement in Atsugewe? Svorou replied that in Atsugewe, movement into a gravitic container means to support or hold things, and that vertical movement is above or below the ground. At this point, Mark interrupted Svorou and stated that he was more interested in general principles, rather than specific examples. Frank restated this, indicating an interest in differences in the categories of containment that were in Svorou's handout, rather than individual examples.

A discussion of "container" vs "enclosure" ensued. Zubin asked if the concepts were size dependent. Svorou said they were; that containers are smaller than enclosures. Talmy disagreed, indicating that function was the difference, that a container supports, holds-in, etc., while an enclosure surrounds. McGranaghan asked about a building's functional role: is a house an enclosure and a prison a container? Talmy said, "Yes."

Svorou also distinguished between partial and complete containment-- the degree of containment. This is handled (sometimes) by a complex post-position. She also noted that there are containment terms applicable to discontinuous containers like nets, cages, and sieves. This is clearly related to conceptions of objects as bounded-unbounded and uniplex-multiplex.

The Lakoff-Johnson ideas about image-schemas and prototypes were mentioned. Mark suggested that prototypes for spatial relations commonly involve type A or B objects, and then the concepts are extended metaphorically to larger-scale objects.

Golledge noted that many words have clearly-defined meanings in visual perception (Types A and B), but become more "fuzzy" in the cognitive domain. We often "go back" to the perceptual domain to try to determine "meaning."

Couclelis noted that the work of Cassirer discusses principles of invariance in visual perception and language. She suggested that the same deep cognitive mechanism may underlie both language and perception.

Tobler returned to his earlier point, that "straight home" is not straight. Frank indicated that Zubin's A and B types are Euclidean and his C and D spaces are non-Euclidean, so "straight home" may describe a more complex geodesic.

MONDAY AFTERNOON

Session 4: Organization of Spatial Knowledge; Knowledge Representation

Stuart Shapiro

Shapiro presented an overview and history of knowledge representation in AI. The basic model of intelligence is to have a database, and an inferencing engine which operates on it. An intelligent entity is assumed to have a knowledge representation and an interpreter.

From the AI point of view, it is important that the system can retrieve not only what was put into the data base, but also has the ability to infer other things.

In the 1970's there was a controversy over whether knowledge is better represented as procedural or declarative structures. In the former case, knowledge would take the form of programs which execute when they are triggered. Terry Winograd was credited with the view that "a word is what one does when one sees it." The alternative was that declarative knowledge was static and used by a program. As an example, most people have only procedural knowledge of the grammars of their native language; they cannot talk about the grammar, but they can use it. Shapiro stated that this debate ended at the end of the 1970's.

Another debate has revolved around whether (image) information is stored by propositional or analog representation. Shapiro counted himself among the propositionalists. Analogical representation seems to require that we know what we are to represent. Operations in the representational medium is an analog to the same operation in the original (represented) medium. Using distances measured from maps to determine distances in the real world would be an example. However, the statement "Santa Barbara is either North or West of Los Angeles" is difficult to represent in an analog (picture) form.

Propositional representation of things in space was seen as being computationally more tractable. It is possible to perform inference on logical rules using prepositions, as opposed to having to define and then perform suitable numerical computations on an analog representation. Analog cannot easily deal with indeterminacy or uncertainty or negation. For example, Han-yong Yuhan's program [see above] would be unable to draw a picture of the theater, even though it could reason about spatial relations in it.

Shapiro's presentations sparked a number of comments and questions.

Helen Couclelis asked how one could make inferences on an analog representation. Shapiro gave an example that "B is 50 miles northwest of A" and "C is 35 miles east of A" can be combined to calculate the distance and direction between B and C. "One hardly notices the inference."

Reg Golledge asked how uncertain data is handled in knowledge representations? Shapiro responded by enumerating several conventions that have been used, including Bayesian statistics (probabilities), statistical inference (Dempster-Shafer), and Zadeh's fuzzy logic. Golledge then made the point that there are analog representations, propositional representations, and reference frames in which there are uncertainties that cannot be resolved-- how can we deal with these? There was no response to this question.

Andrew Frank cited Drew McDermott's use of frames and relations among them. David Mark further commented on frames.

McGranaghan raised the question "can uncertainty in an analog system, such as a range of latitudes within which an island may be located, be represented in a knowledge base? For example, using a gray shaded symbology to indicate an area of uncertainty; or even have probability ranges? Apparently, there were no answers to these questions.

Shapiro compared open world and closed world logic systems. The simplest way to represent lack of information is to not put things into the database. In a closed world system, implicitly used in many databases, anything which is not demonstrably "true" is assumed to be "false"; there is no "I don't know" permitted. AI systems may use an open world system, in which the value of a statement can be "true", "false" or "unknown".

Talmy noted that American Sign Language typically uses location of signs in the analogic space in front of the "speaker" to communicate spatial information, but also has ways to negate such implications.

John Herring

John Herring addressed the way GIS represents data. He indicated that there are fifteen to twenty different ways to represent data, and then concentrated on an object-oriented approach.

In an object-oriented approach, an object has properties including a location and a set of attributes. The location may be specified in a vector or raster form, or as a systematic tesselation such as in a TIN or a grid.

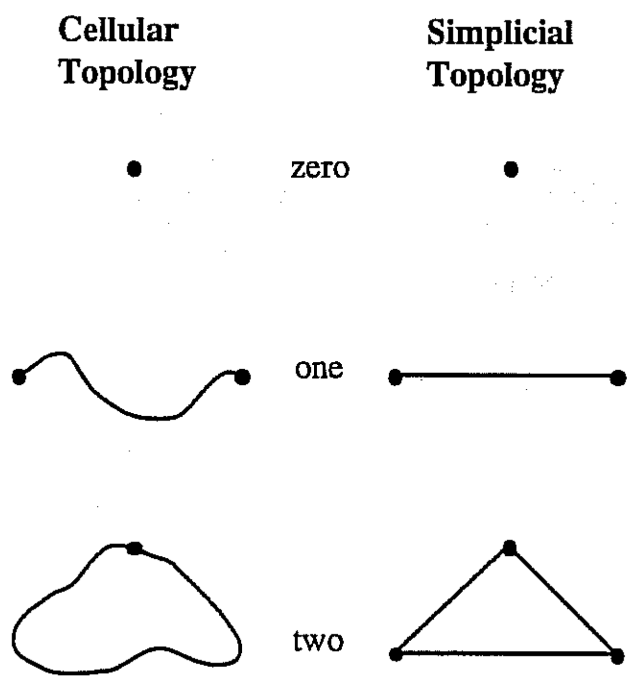

Figure 7: Differences between cellular and simplicial topology.

He commented on schema information and mentioned topology. He made a distinction between simplex and cellular topology (see Figure 7). He noted that Intergraph does not use the National Committee for Digital Cartographic Data Standards (NCDCDS) terminology/model.

The spatial relations among these objects might be expressed in set relations on the interiors and boundaries of the objects (see Figure 8). These relations can be classified by the dimensionality of their intersections. This schema does not accommodate metrical relations such as "near."

There was some discussion of the "disconnected" nature of a purely raster data structure. Someone raised the question "is this sufficient?" To which Waldo Tobler responded, "No!" Herring agreed, noting that the model did not deal with metrical relations at all. Tobler suggested that if you "grow" or expand the boundary of a thing, and it eventually forms a closed figure, then the original thing may for some purposes be considered "closed" itself. Tobler suggested reading the French mathematician, Serra ("Morpologie mathematique"), and also Harry Blum's c. 1970 paper in the Journal of Theoretical Biology.

Peuquet noted that originally, most GISs were developed only to automate the cartographic process. It has only been recently recognized that GISs can be used to manipulate data, perform statistical analysis; i.e., to "tell us" something more about the "space" than what a map can tell us.

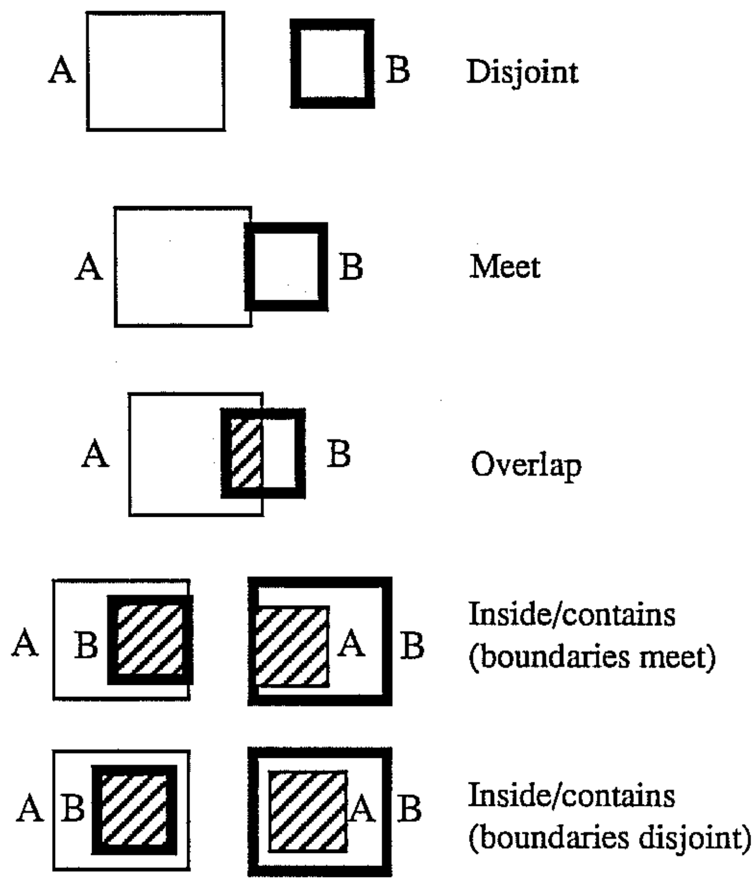

Figure 8: Possible spatial relations between two polygons. (Three other cases are defined if the concept of 'meet' is divided into 'meet at exactly one point' and 'meet along an edge'.)

Session 5: Spatial Relations, Formal Spatial Languages, SQL extensions

Mark Ashworth

Ashworth talked about SQL, and possible extensions to it to handle spatial data and queries. In most GIS, there is one model for one set of information. If a system uses two models, then there is a risk of consistency problems. But, linguistics and spatial knowledge may be different for different human languages. Much of the database industry uses SQL (Structured Query Language) and thus it makes sense to avoid, as much as possible, retraining people as they begin to use GIS. Ashworth stated that, to use todays GISs, the user needs to understand the topology or structure of the data. Ashworth expressed that systems need to be devised in which the user does not have to have knowledge of the structure of the data.

Shapiro noted that the GIS user still will need to learn the kinds of relations and objects that are represented.

Herring raised the question: "What must the user need to know to use the system?" The needs of the database administrator and of the user may be very different, and this difference must not be ignored.

Herring discussed the concept of "operator overload" in which a named operation or function may perform different tasks depending on the operands. Thus an operation like "OVERLAY" may do something different when called with two sets of polygons than when it is called with a polygon and a point pattern. Overloaded operators are common in computing. Users and programmers do not need to know that the "+" operator does very different things for integer and for floating point numbers under most languages and compilers.

Discussion also addressed the issue of the adequacy of SQL for GIS operations. It seemed that at least some extensions would be required. The alternative, to create another query language, may be better from the standpoint of GIS functionality, but it carries the price of retraining those workers who already know and use SQL; also, current commercial database management systems have many capabilities, such as concurrency and data protection, which would have to be re-invented in a geographic database system written from scratch. A compromise is to develop a semi-natural query language for our knowledge domain (geographic information) and to "translate" queries from such a "GIQL" ("Geographic Information Query Language") into SQL for database access.

Shapiro talked briefly about his "Intelligent Multimedia Interface" project. Golledge mentioned a combined tactual-sound system for the blind.

Herring commented that a natural language system capable of translating queries into SQL would seem the best approach at this time.

Golledge raised the idea of having output that is only auditory-- how can tables be described verbally instead of visually?

Egenhofer listed seven requirements for a Spatial Query Language:

1. graphical representation;
2. a means to describe graphical representations;
3. to integrate interactive communication with the image or graphic the screen;
4. combine several results with distinct queries;

5. need for a context in a graphical representation. (For example, when asking "where is Orono?", should one use an outline of the U.S., or of Maine? In other words, what is the context?);
6. need to be able to label points on an image, and this must be directed from the query language; and
7. need for the system to be able to determine the content of a map which is currently being displayed, even if it resulted from several distinct commands or queries.

Talmy raised the question "what can SQL presently do (and not do)? Smyth replied that one cannot ask metric questions such as near, far, etc. Shapiro replied to Smyth's remark by stating that yes, one can ask the question of near; near has to be defined in SQL to enable this. The problem is not with SQL, it is with the representations that "we" have of the terms such as near, far, next to, etc. If we can define them, they can be implemented in a SQL.

Donna Peuquet

Donna Peuquet spoke about her work on modeling geometric relations, and in particular attempting to define a primitive set of spatial relations. She spoke about Jackendoff's approach, which blends logical semantics and natural language, and how that relates to conditions for identifying how two things stand in a given relation to one another. As an example she used the "East of" relation to illustrate three such conditions (see Figure 9).

Zubin suggested that this model is too simple, and that people do not think along these lines, i.e., they don't ask questions in a fashion that would resolve these problems. Peuquet responded that this is only a simple example of how current geometric models, that don't, by themselves, represent how people think in everyday situations, can be extended to (potential) capture the way people do think about such things.

Peuquet also talked about the notion of "graceful degradation" in which, when a perfect match for a query is not found, the system finds an answer or situation which comes close. Her example was "Find a city in central Pennsylvania": should the system find a "city", relaxing "central Pennsylvania", or should it relax "city" and return a populated place close to the center of the state? State College is very close to the geographic center of the state, but may not be considered to be a "city"; Altoona is more clearly a city, but is off center. "Default assignment" (San Diego is near LA, LA is near the ocean, therefore, San Diego is near the ocean) and "spontaneous generalization" were also raised. These relate to the common mistake in "Is Reno east of San Diego?"

We need a set of primitives which is small enough to learn, yet large enough to be expressive.

Zubin noted that there is a basic dichotomy: natural language tends to be extremely context-dependent, whereas technical language strives for context independence.

Talmy noted that gestural languages are "graphic." He also observed that partial overlap never occurs as a preposition in natural language. No natural language is known to have a preposition to use in the following:

*The cloth belapped the table.

Furthermore, attributes rarely overlap in a literal sense in geographic space; overlay is a map-based concept.

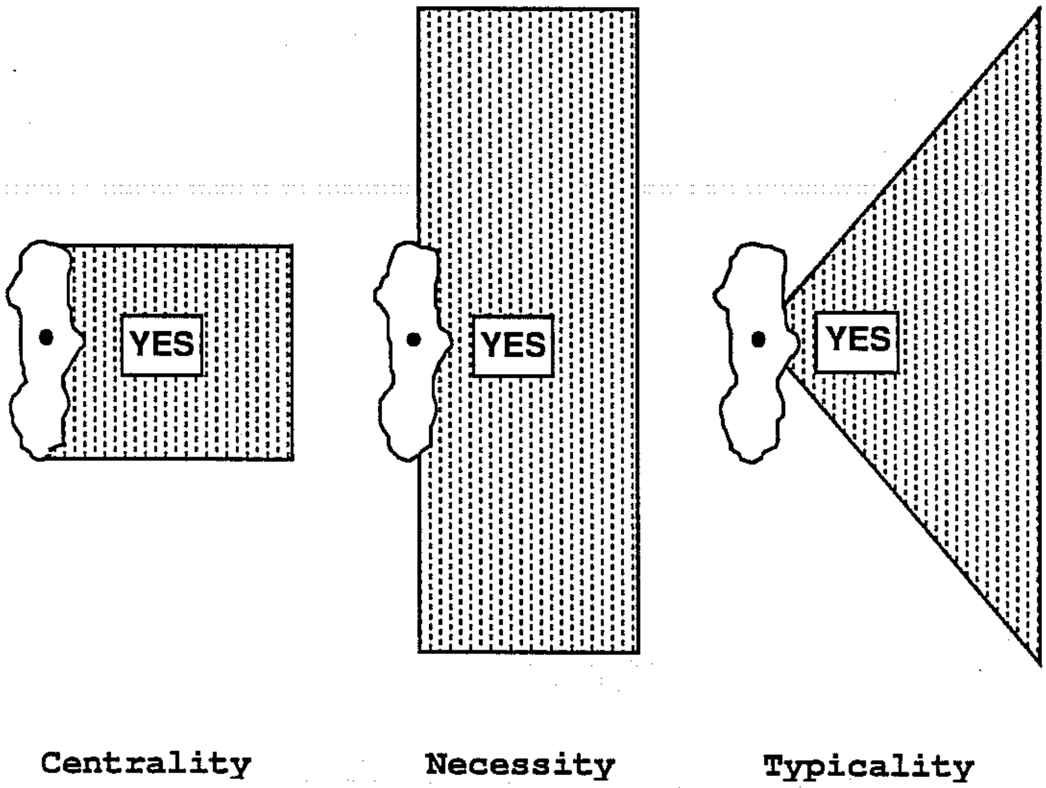

Figure 9: Geographical examples of Jackendoff's principles of what a relation between two objects might be; objects in each shaded region would be considered to lie "east of" the irregular reference polygon assuming north is at the top of the page (diagram after Peuquet).

Max Egenhofer

Max Egenhofer spoke about his attempts to classify the spatial relationships which can exist between different types of spatial objects. He enumerated: topological; directional; metric; and fuzzy or unclear relations. For the latter he offered as examples "close", "far", and "near", which seem to depend on a mix of several of the others (i.e. topology and metric). He noted that not all relations apply to all objects and proposed filling in a table (see Figure 10).

Egenhofer used as an example the interaction between cities, treated as a function of time, as an example; Golledge indicated that interaction is not the same as diffusion.

Examples of operations in each of the domains were discussed. For topological operations, these included "inside", "outside", and "on". Distance calculation was raised in the metrical relations.

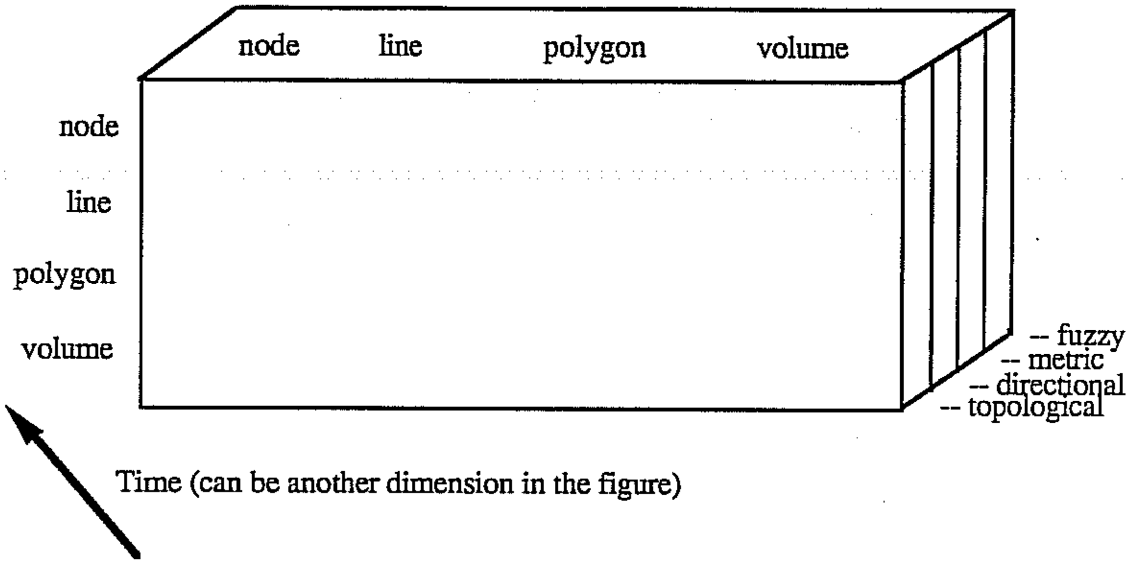

Figure 10: A classification of spatial objects and relations.

MONDAY EVENING

Session 6: Grammars

Tim Nyerges began the evening's discussion of grammars by describing a normative model of the relations among spatially-oriented concepts in a digital map database for his dissertation work. The idea is to "formalize the information organization of map knowledge." He used a "transformational web grammar", a hybridization of Rosenfeld and Pfaltz's "web grammars" and a Chomsky-esque "transformational grammar". In the hybrid, the web records the relations among a set of spatial concepts (deep structure). It is transformational in the sense that concepts in the web may be composed of a hierarchy of components. Some set of primitives is supposed. [Does the model then equate surface structure with map(able) representations of individual objects in space?] Nyerges discussed transformational grammars and productions. He described the basic idea of a grammar as being a quadruple, relating initial elements, rules, non-terminal phrases and terminal elements. Structure may be surface or deep, and content may be explicit or implicit. Nyerges also discussed the difference between social knowledge (including published maps) and personal knowledge. He also discussed the distinction between competence and performance as applied to cartography.

Lang was asked to provide a linguists' definition of grammar. He noted that a grammar has four components: an inventory of elements (the vocabulary or lexicon); a set of rules for combining elements; a set of representations; and a set of constraining principles for production.

Frank again brought up context dependence. On a USGS topographic map, one converts from black rectangular symbols to a continuous pink tone when house density exceeds some threshold.

Zubin remarked on a parallelism between grammars of natural language and the structure of maps. He commented that in discussing the grammar of a natural language it is usual to distinguish between deep and surface structure. In cartography, there is a similar transformation, but there seems to be an effort to minimize the difference.

Peuquet suggested that the surface structure is the map-as-image, composed of marks, colors, symbols, whereas the deep structure is the meaning behind that.

Len Talmy commented that a central idea of a grammar is that a bunch of things are correlated with each other in a complicated way. It relates meaning (conceptual material), strings of words, phonology, vocabulary and syntax. A grammar specifies how all this is done. The Chomskian approach begins with the syntax (patterns) as the central pillar; phonology (on one hand) and meaning (on the other) are secondary. The cognitive approach, however, starts with the concepts (meaning), and sees how this gets represented.

Lang noted that, even if grammatical properties do not strictly apply to maps, the analogy (of map studies to grammar) has heuristic value. On the other hand, he presented some caveats regarding exaggeration of the degree to which the concepts transfer. Unless one can recognize ill-formed structures, or what remains constant under transformations, unless restrictive principles are available, the relation must remain just an analogy.

Bruce Palmer laid out a few premises (assumes that a map is to visual communication as vocabulary is to aural communication) and presented two questions as a basis for discussion. These focused on the notion that maps have a language. There has been considerable work in the semiotics literature.

Len Talmy began a discussion of "language universals." He distinguished between linguistic universals (things which are done the same in all natural languages) and a typology (in which there are few ways of doing things). Universals are often abstract. Researchers usually assume that such properties are innate (we are 'hard-wired' that way), or experiential.

He used the example of descriptions of movement in English and Spanish. In English and all other Indo-European languages except the Romance languages, expressions such as "the bottle floated into the cave" are used. In Spanish and other Romance languages, one must express this in the form: "the bottle went into the cave, floating." The situation is the same for people running down stairs, rocks rolling down hill, etc.

The idea is that there are five components to the expression in any natural language of an "event of motion": the figure (the thing that moved), the fact of motion (moved, relocated), the path (the route taken, a satellite and preposition in English), the ground (what the figure moved relative to), and the circumstance (the manner or cause of the motion). These five components are universal. However, the five are handled and possibly combined differently in different languages. Romance languages, including Spanish, conflate the path with the fact of motion (to in, to out, etc.). English conflates the circumstance with the fact of motion. English does in fact have many path verbs (eg., descend, enter), but these mostly have been "borrowed" from the Romance languages. "Come right back down out from up in there!" could not be expressed in one sentence in Spanish! Atsugewe and Navajo are among the few languages to use a third system, conflating the thing that is moving (figure) into the fact of motion.

The distinction between universals and typology can be used here. The five elements of a description of motion are universal. Typologies arise from noting which of the elements are conflated in different languages.

Palmer then presented a diagram relating concepts of "written word" to their information content, and to the rules that govern them. When "building" a paragraph, Palmer proposed this series: Strokes -> Characters -> Words -> Sentences -> Paragraphs. As one moves from strokes to paragraphs, the information content changes from low/simple to high/complex, and the related rules change from "many" for strokes and "few" for characters, words, sentences, and paragraphs. From this, Palmer raised some questions:

1. Does visual information follow a hierarchical information layering?
2. What are the levels of visual information?
3. What does the visual information content look? How do simple graphics convey complex ideas?
4. Visual dictionaries would seem useful; what concepts are useful?
5. Pertaining to dictionaries: How are they compile? How are circular definitions avoided?

Palmer contended that we "seem" to use the same mechanisms for interpreting visual information that we use for understanding language.

TUESDAY MORNING

Session 7: Spatial Cognition

Helen Couclelis

Couclelis asked first "Does GIS need language analysis?" and she answered, probably not, for most routine applications. She referred to Peter Gould's paper at the June meeting (see NCGIA report 88-6) in which he makes just that argument. Even mainstream applications however may often benefit from a natural language interface for either input or output, and in some cases (e.g., in portable navigation systems for the blind) a linguistic interface may be required. The next question then is, could the simulation of linguistic performance (as opposed to competence) be good enough for such purposes? This 'black box' approach may be successful up to a point, but as with all black-box approaches, you never know when it is going to break down. Ideally, we would like to be able to simulate the mechanisms that generate linguistic behavior, rather than just their output: hence the interest of this Research Initiative in linguistics, motivated by the assumption that insights from language analysis can be directly used in GIS. This brings up a third question: how compatible is natural language with computation? Recent work in cognitive linguistics and other areas suggests that bringing the two together may be harder than we think.

Couclelis then focused on spatial image schemas and what they may reveal about spatial cognition. Recent research suggests that they are 'imposed' on reality, that is, the direction of fit is from image to world, not vice-versa. Spatial image schemas are largely based on pre-existing world knowledge that has physical, biological and also cultural roots. The question of how that knowledge got there is generally unanswered, and from the point of view of AI approaches, it is irrelevant; yet, biological and other studies suggest that the question is crucial. Some key references were mentioned at that point: Lakoff's 'experiential' paradigm dealing with language and cognition assumes that there is an objective world, but that its features are nature- and culture-specific. In particular, language is metaphoric, the metaphors being rooted in the everyday physical/physiological world. Herskovits identifies the image schemas behind some locative expressions, consisting of geometrical idealizations and allowed deviations from these. Edelmann, an evolutionary biologist, stresses the importance of 'hard-wired' world knowledge in the neurological mechanisms of learning, and is critical of AI and 'neural nets' approaches. Finally, Couclelis and Gale have described an algebraic hierarchy of qualitatively different spaces that could help integrate the kinds of insights mentioned above.

The sequence of spaces identified are (1) Euclidean, (2) physical, (3) sensorimotor, (4) perceptual, (5) conceptual, and (6) symbolic. The transition from one space to the next is accomplished by adding a new set of attributes to the objects and operations already defined, and this modifies the algebraic properties of the space. For example, by adding the notions of time, force, and mass to Euclidean space, the latter is transformed into physical space, where we can describe the movement of physical bodies.

At first sight, that sequence of spaces shows a good correspondence with different components or aspects of spatial cognition. Couclelis gave examples for the individual spaces. Physical space is the source for deeply engrained intuitions such as the 'flat earth', the sky as a dome, the notion that things always drop straight down, and for 'naive physics' in general. It is also at the origin of the basic object types identified in studies on categorization. Sensorimotor space is at the basis of the 'object schemas' described by Lakoff. Perceptual space has its own distinctive properties that underlie phenomena as disparate as vision, language, and music understanding. Conceptual space hosts propositional knowledge and information processing.

The main point is that, whereas much of spatial cognition is already in place by the time we reach the conceptual level, the levels preceding it do not seem amenable to a computational representation. This is because the elementary entities at these levels are already complex--they are 'gestalts', and as such they already have an inherent meaning. This is why the task of using computational methods to simulate linguistic competence is so hard. Couclelis claimed that current computational approaches are not appropriate, in particular 'Von Neumann' (algorithmic) approaches, because they cannot deal with symbols that are both internally structured and meaningful. Connectionist approaches offer some promise, but Edelmann is very critical of them too.

During the discussion, Nyerges asked where Edelmann's work is situated and Couclelis explained that it is at the physical and sensorimotor level. Edelmann too proposes the use of hierarchical systems and mechanisms to select relevant information in learning such that useless inferences are reduced.

Couclelis discussed another potential problem: How does one stop a system that "knows" a lot of things from inferring vast numbers of irrelevant facts? Many functions in higher animals become selectively "hard-wired" during the first few weeks or months of life, depending on what experiences are particularly relevant for the species or individual in question.

Zubin mentioned the neurophysiological insight brought to the problem and how extensive these influences are. He asked whether these influences are relevant. Golledge stated that such factors may provide insight into gender-based differences.

Couclelis explained that cognitive structures on lower levels cannot be represented in propositional form. Zubin referred to Lakoff's attacks on the notion of computational models of human cognition.

Couclelis stated that the problem cannot be solved based upon set theory or something close to it. The problem is the atomistic view of the world, which assumes that undecomposable elements are by definition simple ('atoms').

Zubin stated that digitally recorded music, now commonly available on compact disks (CDs), breaks sound into atomic pieces, but it can be put together again. This is a transition into discrete space, yet a reconstruction into continuous space, such that it sounds correct.

Couclelis mentioned that, in the space-hierarchy described, the group structure breaks down beyond physical space. Therefore, geometry in Klein's sense cannot be defined there.

Guevara asked whether GIS needs language. He stated that studies are needed of how users interact with a GIS. No one has explored this question so far. In particular, the dependence of interaction based upon different cultures is an important aspect for him.

Talmy and Zubin asked what is universal in image schemas.

Mark suggested that the finding of universals relevant to GIS may be a research question to be explored within 18 months. Frank agreed that language universals are a key idea here. What image-schemas are universal? In particular, what are the universals in the GIS domain? Frank asked whether natural language is a good vehicle for GIS. He suggested that where one needs more precision, one uses highly structured, restricted languages.

McGranaghan stimulated a lively discussion about the expression "The sun came up", indicating that "We spun toward the Sun" better approximated the physical reality. He asked whether a formal, structured language would be useful for several different schemas, e.g., the Earth spinning vs. the Earth stationary and the sun moving.

Zubin: "That's the whole point of the experiential revolution in concept formation. Let's get the theoretical issue clear. In the objectivist view, there is a true situation which is that the Earth is spinning toward the sun, and then there's a mistaken, or limited, or primitive view, (all of those, limited, primitive, and mistaken) which is that the sun is rising. Now the experiential hypothesis about reality and about the world concepts is that, given any particular perspective, there are particular schemas that are useful for conceptualizing it, for conceptualizing your experiential world, and other schemas that are not. Now, given our activities on the Earth, the schema of the sun rising and setting is a useful one; the schema that the Earth is rotating toward the sun is not a useful one. It's bad. Not useful. Now, given the perspective of a satellite, sufficiently distant from both the sun and the Earth, looking at both of them, the schema of the Earth rotating toward the sun is a useful one, and the schema of the sun rising is not. It's a point that you can always find a domain of investigation where one schema rather than another is useful. It's not an issue of whether one of them is right or not, but of how useful it is."

Shapiro mentioned that remembering whether it is earlier in the day or later on the other coast can be conceptualized as the sun rising in the east and moving westward. Zubin said that that is exactly what he does to work that out.

McGranaghan, assuming a database model in which there is an underlying data-organization which might be called upon to support several sub-schemas, or ways of looking at the modeled reality, asked: "How should a database know which schema it should be applying right now?" Zubin: "Well, that's the issue, not to say that one is right, and the others wrong."

Reg Golledge

Golledge started with the statement that it is probably a very good strategy to break the world into understandable chunks. It is necessary to understand what a spatial knowledge structure is and what such a structure is capable of containing. World knowledge is filtered through the senses.

Golledge mentioned the lack of comprehension of spatial knowledge and gave an example of children in a city environment. These children were not able to find a direct, shorter way in a pattern of parallel streets than the one they were used to go, and instead chose the familiar, but long way.

Landmark or declarative knowledge is of the "what is where"? type. Golledge mentioned five fundamental descriptors of external reality: (1) equality (or identity), (2) measurements, (3) location, (4) magnitude, and (5) temporal existence. Each of them can be used specifically (i.e., precisely) or not. Location, for example, can be imprecise, magnitude can be fuzzy ("a lot," "many"), time can be precise (i.e., clock time), but there are other, less precise expressions as well. Moreover, the four concepts can be combined, such as distance and time.

Regionalization of information leads to a hierarchy, with anchor nodes. Golledge stated that breaking something down into parts is a natural process, but in the spatial sense a reassembling might be impossible. He identified three levels of spatial knowledge: (1) declarative base (inventory), (2) procedural level, and (3) configurational knowledge. The latter is more than linking procedural rules and the declarative basis, but not clearly understood. The moment things are perceived on a map, their locations become understandable. Golledge presented some research with children and some adults in a suburban neighborhood. Subjects learned two routes, with partial overlap, and then were asked to judge distances both within and between routes. Subjects also were shown slides, and asked whether they were on the learned routes or not, and other related questions.

In the remainder of his talk, Golledge concentrated on spatial comprehension by the blind. He is investigating whether the blind (from birth) can achieve the same level of spatial knowledge and comprehension as the non-blind or people who lose their sight later in life do. He identified a two-level task: (1) can they perform simple directional tasks, and (2) can individuals put together line segments and angles to geometric figures, such as triangles?

Session 8: Navigation, Spatial Inference

Jack Loomis

Loomis introduced the experiments he is doing with Golledge, investigating the basic skills of blind or blind-folded people moving in small space. He showed a video of their experiments in which a blind person is directed by synthesized stereo sound in order to find objects in the small space (5-8 meters). Two cues for distance (volume and pitch) and two cues for direction (inter-aural time and inter-aural intensity) are used. The experiments showed that people perceive directions faster and more precisely than distances. Results are being used to design navigation aids for the blind, using synthesized stereo sound to produce virtual sound sources as navigation aids.

Suchi Gopal

Gopal presented her investigations about types of errors in spatial inference for human way finding. From the literature, she presented Kuipers' model of view and action which is fundamental and used by many researchers in the navigation area, and Piaget's observations that children have problems retracing a path in reverse order. Gopal mentioned that an error in navigation is normally a deviation from the path or a confusion error. Errors accumulate at decision points and at the start or the end. Also, start and end mental maps are more detailed, thus leading to more errors. She presented her own navigation model which consists of two modules, (1) the objective environment, and (2) subjective environment. She identified four types of errors: (1) inadequate representation in the long term memory, (2) salient but irrelevant information retrieval (faulty route planning), (3) largest confusion error is selecting the wrong target, and (4) representation and subsequent decay.

Freundschuh raised two points. The first is that Kuipers' first level of spatial knowledge, sensorimotor knowledge, combines both Golledge's declarative (landmark) knowledge and procedural knowledge. Kuipers' model indicates that landmark knowledge is acquired as a consequence of acquiring route knowledge, i.e., they are dependent. In contrast to this, Golledge's model does not imply this dependency. In Golledge's model, the mode of acquisition of landmark knowledge is not a factor. Freundschuh questioned whether the mode of acquisition of landmark knowledge should be ignored. If a large proportion of landmark knowledge is acquired as a consequence of learning routes and paths, it is possible that the two types of knowledge do not exist separately, but instead are one. Golledge replied that we do acquire declarative knowledge via means other than navigation, and that yes, they (declarative and procedural) are two different kinds of spatial knowledge. He further stated that we "build" procedural knowledge based upon declarative knowledge.

Secondly, Freundschuh mentioned that adults suffer from the same disabilities that children do, so Piaget's model is also applicable for adults.

Zubin noted that many experiments model competence for adults, and then test performance in children, and conclude that the children cannot do as well. But when performance is tested in adults, they may do no better than children do.

There was some discussion of the mental models of space that are needed to support navigation. Talmy discussed the Micronesian systems, and Couclelis mentioned medieval, non-Euclidean models of space.

Terry Smith

Smith presented some ideas for reasoning about spatial relationships. As example he used the direction relation NORTH. From the transitivity property of NORTH one can conclude that if A is NORTH of B, and B is NORTH of C, then A must be NORTH of C as well. He proposed to examine other properties, such as reflexivity, and symmetry.

Frank proposed to define a number of systems, to investigate their power, to run experiments, and apply them to way finding, for instance. Lang mentioned that the pairs of relations "far" and "near" are not exactly converse because "not far" does not imply near, but "not near" implies "far." Zubin and McGranaghan mentioned that there are terms for tall and small persons, but no size term in English for "normal" persons. They concluded that such a term does not exist because it is not needed. Nyerges mentioned that we might mix different concepts of spaces.

TUESDAY AFTERNOON

Session 9: Understanding Geographic Language

Matt McGranaghan

McGranaghan talked about automating the interpretation of narrative descriptions of locations from which herbarium specimens were collected. These descriptions include place names and textual passages describing the location, but not coordinate information. His concern in this presentation was parsing the descriptive text, with the intent of deriving coordinates by identifying things in the text which can be located in standard USGS data sets.

He briefly introduced the concept of grammars as compositions of rules, starting units, phrases, and words. Smith mentioned Fu's book on spatial grammar which Frank judged as not directly applicable. Frank also mentioned the use of L-grammars which were used for production rules of plants. Couclelis stated that anything that can be mapped upon a tree structure can be treated as L-grammar.

McGranaghan noted that the descriptions are composed of combinations of spatial relations, such as "along Waikane-Schofield Trail, at the bottom of the cliff", and that locations could be limited by reasoning about the named objects and their spatial relationships. Zubin wondered whether it is important that something referred to in the text is found on a map, or whether the user must actually go out in the field to identify the object. He stated that the differences between reality and maps may be crucial. McGranaghan agreed that the generalization inherent in maps and digital data bases should be kept in mind. He went on to point out that many of the named features in the descriptions seem to have been drawn from USGS topographic map sheets by botanists in the field. Thus, a data base such as the USGS GNIS is very useful in recovering coordinate information.

Steve Smyth

Smyth talked about building systems you can model for specific purposes. In such systems, mappings between models are important. Such geographic modeling systems have a clear concept of modeling and are not map maintenance systems. The realm of these systems is the combination of objects and operations plus the purpose of the model the system is built for.

As an example for such a systems, Smyth mentioned a system for deed descriptions. Such a system contains two descriptions (text and the survey plat) that are linked logically. For each part, a language is needed. The graphical language can consist of points, lines, and areas, while the textual part can use the deed description terminology. The system was referred to as TAG-X, where "TAG" stands for "Text And Graphics", and "X" would be the acronym fo the particular application.

Michael White

White presented problems associated with formalizing deed descriptions. These descriptions contain references to monuments, either physical or non-physical. The descriptions are sequential from a start point along the boundary, back to the point of beginning. The language used is more or less formal, since these deeds are normally written by lawyers or surveyors. The courts give specific meanings to certain expressions. Evidence is derived by a hierarchical set of rules, in which very weak confidence is put into measurements.

The actual description is influenced also by the description of the surrounding parcels and earlier deeds. So it is necessary to construct the geometry from multiple descriptions. Important questions are (1) what is the model, (2) why did the system with restricted terminology evolve, (3) why did they use written language (opposed to maps), and (4) can a procedural description be reduced to a canonical term? These questions relate to uncertainty and how to treat redundancy.

Session 10: User Interfaces

Jan van Roessel

Van Roessel discussed the role of non-spatial attributes in a spatial information system. He concentrated on overlay analysis. His data model is a cover that consists of an infinite number of points with attributes. He exploits the relational schema with spatial attributes and object keys. The definition of an object needs equivalence classes of points with same attributes. This can be achieved in almost any programming language, and does not need special spatial modifications to existing languages.

Van Roessel divides the attribute set into two sets: (1) attributes that are used to define objects (homogeneous), and (2) other attributes (heterogeneous). Overlay becomes then a join in which heterogeneous attributes may disappear, if discarded deliberately in the attribute transformation process, or if they are made part of the attributes that define the output spatial object.

He mentioned several interesting research questions: (1) What inferences are possible with spatial operations? He has plans to compare the operators to Dana Tomlin's overlay operations. (2) How do properties propagate? (3) What are implications for raster/vector systems?

Guevara said that he worked on this problem with computational implementation. Van Roessel was not opposed to computational/ implementation solutions. However, we first should develop a general abstract model that is implementation-independent, and only then begin to explore implementation itself and its ramifications.

Guevara presented a schema for an adaptive model. It is based upon a generic functional model with basic primitives (0-, 1-, and 2-cells) and operations. At a higher level, spatial objects are treated including operations, such as overlay. On top of this level is a spatial language which serves as interface to an "adaptive spatial processing architecture." He raised the question whether the operations on raster and vector are the same. Frank proposed that model and operation should be combined at low level. Guevara wants to integrate all sorts of models and data types. Cultural differences should be considered at higher levels, as well as spatial application types. Egenhofer asked whether we should first understand users' needs. He proposed the development of a model of the GIS user. Guevara stated that important issues are which components make a good spatial language, e.g., icons, actions, etc.

Len Talmy

Talmy discussed universals of spatial languages and presented the following concepts that occur in all languages:

a point space located	at a point of space	
a point space moves	to a point of space	at a point of time
a point space moves	from a point of space	at a point of time
a point space moves	through a point of space	at a point of time
a point space moves	along an unbounded space	for an extent of time
a point space moves	alength a bounded space	in an extent of time

The first element in each of these is the figure while the second thing named is the ground. There may be a choice of ground configurations.

Talmy also described several distinctions about motion "out." A point may move out of an area. A ring (as of fire) may move out of an area, leaving an empty middle. Also movement "out" may, like oil, spread out over an increasing area. Talmy's paper on "How Language Structures Space" (p. 277-278) contains 20 parameters describing a figure, the ground, and their relation that are relevant to the domain of closed-class elements that are expressed as prepositions and deictics in English.

Max Egenhofer

Egenhofer gave a brief introduction to human interfaces and the importance for GIS. He stated that research is necessary in order to make the interaction between the user and a system smoother. In this research, humans are the center of the investigation. An appropriate way of designing a GIS would be to first design the human interface, and then to investigate what is happening underneath it. Unfortunately, normally the reverse is done, namely a human interface is put on top of an implementation. The disadvantage of this approach is the fact such interfaces show the internals of the system construction.

Human interfaces have always been there-- they just are not well designed. Historically, human interfaces became popular with the development of the XEROX star interface which introduced multiple windows, graphics, and a pointing device. These tools revolutionized human-computer interaction which had been driven by batch processing before. New paradigms were developed, such as WYSIWYG (What-you-see-is-what-you-get) providing interaction, direct manipulation, and feedback.

Egenhofer claimed that the differences between the interaction with a conventional system and a GIS are based upon the combination of graphical and alphanumeric data. Both types of data must be considered in the interaction. This requires integration for interaction (input) and representation (output).

User interfaces must be implemented and tried out in order to be evaluated. There is nothing like a metric for our interfaces-- the users define whether an interface is good or not. Some tools exist, such as user interface management systems or HyperCard. Nyerges recommended Foley's tools. Peuquet asked whether the tools should influence the interface or rather an interface be designed and then the tools be adapted. Palmer complained that primitives in existing tools, such as graphic packages, are not suitable for GIS. Nyerges and McGranaghan asked whether user interfaces and their models should be independent from the implementations.

The discussion about metaphors, like the Macintosh "desk top", and icons, such as the "trash can," lead to the question of what would be appropriate metaphors for a GIS.

David Embley

Embley talked about the use of visual language for the interaction with a GIS. His background was work on top of database models and navigating in them. In his Semantic Data Model Organization, he considered entity-relationship diagrams, heterogeneous collections of objects, and spatial relations. As an example he presented some interface snapshots for the update of electric power distribution plans. The language used extensively menus and buttons. Frank asked to which degree this could be considered a language.

Embley concluded with a set of important issues: (1) spatial semantic context, which will help to establish the meaning of, eg., "near;" (2) mixed mode interaction; (3) object properties and constraints; (3) context abstraction (zoom, pan in context) and abstraction of object; (4) uniformity in interface.

Stuart Shapiro

Shapiro showed a similar example of interface snapshots from a DARPA project he has been working on. He used the analogy of people talking to each other while standing at a blackboard. The interaction is in graphics, text, speech, pointing and gesture. AI techniques are used to help the user. Goals in the design of the interface were to maintain context and consistency. The system includes only query facilities, no tools for manipulation. It is built on SNePS, a propositional semantic network.

Multiple input devices, such as voice and pointing with a mouse, are used. This combination may lead to contradictions, which the system must resolve.

McGranaghan stated that the user task model must be shown. Large menus are painful, and natural language seems to select things fast.

Zubin mentioned that linguistics were involved in the SNePS project. He proposed that the best solution is the integration of linguists into the project.

Nyerges complained that cartographers are not integrated into the map design process.

Shapiro expressed hopes that his presentation wakes up interest and that cartographers start looking at it.

Talmy stated that linguists could contribute to the discourse.

Nyerges thought that the investigation of universals in visual languages may be an important research question.

Talmy stated that the bottleneck is the understanding of language.

David Mark

Mark talked about urban way-finding, and presented several answers he got from people describing the way to the UCSB campus in natural language. He found out that they used gestures, landmarks, and up/down images. None of 18 subjects interviewed in three cities referred to a map or tried to make a sketch, although some made hand gestures that might be considered to be "maps in the air". Egenhofer mentioned an observation that Europeans in general can show a way on a map, while, in his experience, Americans always avoided the map and used natural language. Mark asked whether the shortest description really describes the easiest way. Palmer asked whether people with more visual information could draw a map better.

WEDNESDAY MORNING

The final full day of the Specialist meeting was mainly devoted to Working Groups. However, the day began with a presentation by Robin Fegeas of the U.S. Geological Survey, regarding that Agency's programs and research interests in relation to GIS and spatial language.

Robin Fegeas

Fegeas discussed the National Digital Cartographic Database. Geographic data from a variety of sources are digitized and entered into the data base. Then, data from the NDCDB are used in two distinct ways. In one track, symbols are chosen to represent the data as printed topographic and other maps are produced. In the other track, data are distributed in machine-readable form to GIS users. Current products include topographic maps, Digital Line Graphs (DLG), Digital Elevation Models (DEM), and the Geographic Names Information System (GNIS). The USGS solicits assistance with defining GIS user requirements for data from NDCDB.

The NDCDB is based on the following sequence of abstractions or models: reality -> data reality -> data model -> data structure -> file structure. At present, the data reality assumption of this approach assumes: (1) the real world (rather than map) as the objective of the model; (2) an earth-surface phenomenon structure; and (3) data at a single point in time. They intend to add: (4) true networks (to support flow studies); (5) three-dimensional spatial data (subsurface); and (6) space-time data.

The new DLG-E files will have about 260 feature classes for cartographic objects. USGS hopes eventually to support a variety of "views" of geographic data, including: cover (a surface structure), division, ecosystem, geoposition (including elevation), and morphological views. Is this appropriate?

Fegeas listed the following USGS "needs":

1. Model(s) of "real-world" (physical?) spatial phenomena;
2. Model(s) of conceptualizations of spatial phenomena;
3. Methods of feature/attribute classification and definition;
4. Methods for mapping from definitions of spatial phenomena to formal representations and models;

5. Integration of formal models (raster/vector, static/dynamic, planar/nonplanar, etc.).

There is a cost-benefit aspect to the relation between conceptual issues and objective ones; the more thoroughly we probe the conceptual, the more difficult the path to objectivity.

WEDNESDAY MORNING WORKING GROUPS

Working Group on Spatial Relations

Peuquet (leader), Herring, Shapiro, Van Roessel, Lang, Egenhofer, White, Embley, Fegeas, Smyth, McGranaghan, Gopal.

Peuquet began by presenting some ideas on a dual model of spatial knowledge representation as a basis for the discussion. On the image-based side, operations can be grouped into geometric relations, generalization/ specialization, and overlay. Corresponding operation groups can be found on the object-based side. This lead to a discussion on how to classify operations, and how to classify spaces. 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. Herring suggested that this does not answer peoples conceptions of space. Herring suggested as a first topic Stuart Shapiro's idea of restricting a problem to one dimension and solving it adequately for this limited case first. He suggested as a second topic defining an ontology. Herring suggested as a third topic investigating the relations between metric and quasi-metric spaces. Embley saw three directions: (1) objects, ontology; (2) view space (eg. 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. Herring suggested researching the integration problem in raster/vector GIS, i.e. how to make this invisible to the user.

Working Group on Language Universals

Palmer (leader), Frank, Freundschuh, Mark, Nyerges, Svorou, Talmy, Zubin.

There may be a level of universal concepts, all the features that could be. Any particular language groups these in various ways into image schemas.

Researchable Questions:

1. What are the translations between graphical language and natural language?

2. What can't imaging schemas model? (That is, what spatial situations cannot be modelled by image schemas?)

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

4. 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.

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

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

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

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

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

10. What are universal constructs of space?

11. 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.

12. 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.)

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

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

15. 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.

16. 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.)

WEDNESDAY AFTERNOON WORKING GROUPS

Working Group on Spaces

Frank (leader), Couclelis, Gopal, Mark, Zubin

Researchable Questions:

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

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

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

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

5. 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.)

6. How do these ideas relate to graphic communication?

7. 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?

8. Coordinate research on spatial language for small-scale spaces (cf. Lang) with work on large-scale (geographic) spaces.

9. Investigate the use of image-schemas for default spatial inference with incomplete knowledge. A particular example involve the combination of the part-whole image-schema with geographic hierarchy, which usually works but occasionally produces errors such as "Reno is east of San Diego". (a c A) + (b c B) + East_Of(B,A)==TRUE --> East_Of(b,a)

Working Group on Spatial Inferencing

Egenhofer (leader), Embley, Fegeas, Herring, Lang, Peuquet, Van Roessel, Smith, White.

Herring asked what we understand by spatial inference, and Egenhofer gave the definition that spatial inference is the way higher spatial knowledge can be derived formally from less complex spatial knowledge. Herring concluded that most of the inferencing problems could be solved by considering an algebra for a space. This algebra contains the properties about the relations and allows for reasoning according to well-known rules. He gave a simple example for an algebra consisting of a set of symbols (intersect, equal), and the definition of an operation in terms of the symbols and Boolean operators (overlap == intersect AND NOT equal).

The group agreed quickly that the mechanisms to infer depend upon the space and its properties. Herring sketched a framework in which the algebraic approach can be combined with the space dependencies (see Figure 11).

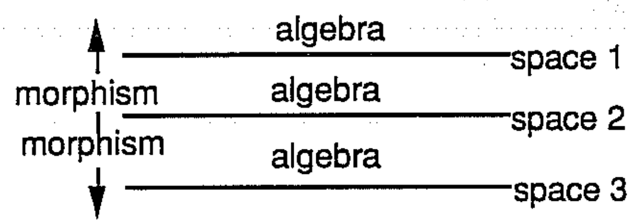

Figure 11: Spaces, morphisms, algebras.

Each space is defined by an algebra, and mappings between each space are achieved by morphisms. As an example, the topological and the metric space were used. The algebra uses properties which are specific for each space. For instance, the topological space is based upon primitives, such as boundary, interior, and dimension. The metric space, on the other hand, has the primitive "distance."

Based upon this framework, several research questions were defined, which could be investigated with 12-24 months.

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:

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

   1.1. define unary operators

   1.2. reduce the operators to a minimal set

   1.3. 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.

   1.4. 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. Combination of spaces by combining algebras, so-called cross-morphisms (Herring). This question relates to the Reno problem where a state is south of another state, but a city, contained in the first state, is not south 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.

4. 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.

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

8. 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., where the house number gives a spatial information.

9. Given geometric data, inference of attribute data (Van Roessel).

10. 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.

11. How to deal with overdetermined 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 overdetermined or contradicting structures, such as topology.

Working Group on Visual Grammars

Nyerges (leader), McGranaghan, Palmer, Smyth

The discussion started off on the the topic of grammars related to graphic production versus imaging schemas related to image interpretation. Palmer and Nyerges started talking about the importance of understanding artificial versus natural visual images. Maps were included in the artificial images (scenes). McGranaghan wanted to discuss principles of a spatial/geographic grammar-- rules about how component parts are put together to form the whole. This might include shape grammars, but the interesting thing is permissible combinations of things (land-uses, physical features etc) in space. Are there limits on what can be close? Coincident? If not then the ensemble of stuff in space is essentially random and therefore not very amenable to reduction through any grammar-based approaches. Nyerges and Palmer continued to emphasize imaging schemas because grammars were considered too restrictive for dealing with a scene.

Visual Grammars-- a set of rules and elements for creating permissible combinations of elements.

Visual Imaging Schemas-- schemas used to perform interpretation. They provide a structuring of the implicit relationships among explicit relationships.

This lead to the first topic:

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

This lead to a second topic:

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

We discussed whether the spatial forms related to specific features within particular types of schemas would be possible to elicit from a subject. Perhaps this information might be useful for the lineage information to be stored for making inferences about the accuracy of the data in the database. It was suggested that this might weed out the temporal confusion in some of the data as it had been compiled.

Discussion started to focus on the distortions in databases. It was suggested that sometimes distortion is needed, e.g. in a cartogram. This lead to the next topic on the influences of "size distortion" on the meaning of information. It was noted that this has already been researched in the psychological/psychophysical literature.

This lead to the next topic:

3. 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?

Discussion started to stray so we agreed to come back to the visual grammar focus. We started to discussion how maps are interpreted in a general way. This lead to the next topic:

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

This brought up the related topic of:

5. 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. This lead to the next topic:

6. 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. After some discussion about the feasibility of capturing image schemas it was decided that the topic should be postponed to another time in order to identify other topics.

The next topic discussed involved distortions in the information transferral process form the cartographer data compiler to the output product.

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

This lead to a related topic:

8. What is there about spatial form that is possible to symbolize when showing data quality information. This topic is part of another initiative.

Several types of scenes were discussed. These different scenes lead to a suggestion about different displays being generated.

9. 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?

This discussion lead back to the difference between grammars for scene generation versus image schemas for interpretation. This lead to the next topic:

10. 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. These differ from imaging schemas because they are used to generate visual depictions of a scene. Imaging schemas are used to interpret scenes/maps.

Discussion was turned to the visual cues in a scene.

11a. What categories of visual cues are necessary for interpreting each of the "alphabet" (Types A-B-C-D) spaces as presented by David Zubin.

11b. Can cues be enumerated from specialist areas and used for interpreting the utility of "alphabet" spaces?

11c. 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 (eg. shadowing in terrain simulation)?

12. What reference cues can be added to "impossible 3-D objects" to make them look like "realistic" landuse or other kinds of maps?

Working Group on Navigation, Way-finding, and Geographic (Direction-giving) Language

Freundschuh (leader), Talmy, Shapiro, Svorou, Flury.

We identified long range research topics, which are broken down into sub-research topics. Several of the sub-research topics are manageable within an 18 month time frame. The research topics that this small group proposes have been categorized under two headings: Spatial Knowledge Acquisition and Direction Giving and Receiving.

I. Spatial Knowledge Acquisition

Golledge has defined three kinds of spatial knowledge called Declarative Knowledge, Procedural Knowledge, and Configurational Knowledge. Possible research topics are:

1. 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".

2. To 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.

3. To explore the use of "spatial stereotypes" to aid navigation for both blind and sighted navigators. Spatial stereotypes is a term used by Flury (I do not know if this term is used in the literature) which uses 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 is 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?'.

II. Direction Giving (generation) and Receiving (processing)

A. Automated (computer generated) Directions

We discussed automated generation of directions by trying to identify what "things" a computer would need to enable generation of useful directions.

1. Data base issues: what information is required for the data base?
   - Selecting the route: select the shortest path, or the easiest path?
   - Selecting 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. Out of this falls two questions: how can important landmarks be determined?, and how should a weighting scheme for salient landmarks be designed?

2. Need to design algorithms for generating natural language navigation cues.

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

4. 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. (Reg Golledge mentioned this during his talk)

B. Human Generated Directions

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

The Giver of Directions

1. 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

1. 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.

2. Are navigation cues different for navigation during the day vs navigation at night?

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

General Issues

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

2. Do directions change when given for a city (large scale) vs 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; not recognizable to a stranger who happens upon the town.

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

4. 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 N [or S, E, W]" whereas directions in a smaller scale space tend toward the use of "go left", "go right"?

5. 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).

APPENDIX A:
POSITION PAPERS SUBMITTED AFTER THE MEETING BY PARTICIPANTS

A-1: The Category Model of Spatial Paradigms

Dr. John R. Herring
Intergraph Corporation

In investigating the theory of spatial relations, there are three areas for each representational view or paradigm that must be researched. These areas are:

o the logical view of the spatial representations, the way in which space is organized

o the features/objects that are representable within this view

o the spatial operations/relations that can exist for these features within this view, and the rules for their combination, and manipulation (their algebra)

In systems that deal with more than one representational paradigms, the mappings (morphisms) between these inherent concepts must also be understood, for it is the morphisms that allow questions and answers to pass between the differing paradigms.

Views of Spatial Representation

Each spatial method of representation adopts a fundamental paradigm for handling spatial concepts, and for organizing spatial objects and the relationships that "exist" between them. Some of these views are quite precise in their meanings and formal in their syntax (the geometries, formal query languages), while others are informal and fuzzily defined and thus subject to more variation in interpretation (natural languages).

Some of the known paradigms, and their more important underlying concepts, are included in the following examples:

o Topological spaces
- open and closed sets
- boundaries and interiors
- points and location
- curves as continuous images of lines
- surfaces as continuous images of planes
- homeomorphisms (continuity-preserving)
- compact sets (as defined by a finite open sub-covering condition)
- dimension (a topological invariant, although not definable in strict topological terms, see the Invariance of Domain Theorem in the topological literature)
- connected

o Metric space
- all topological concepts
- a globally defined distance function
- bounded sets
- isometries (metric preserving)

o Gaussian geometric spaces
- all topological and metric space concepts (using limits and integrals)
- local coordinate systems (possibly a global curvilinear coordinate systems)
- Gaussian curvature tensors
- arc (curve) length (defined as an integral)
- geodesics and curves (generally parameterized by arc-length)
- curvilinear polygons and surfaces
- locally valid direction (tangent vectors)
- isometries (geodesic-preserving)

o Euclidean geometric space
- all topological, metric and Gaussian concepts
- a globally valid rectilinear coordinate systems (with a flat Gaussian curvature tensor)
- lines (geodesics with respect to the Gaussian curvature)
- globally valid and transitive direction
- affine transformations (line-preserving)

o Raster space
- location
- pixels and pixel sets
- neighbors

o "Propositional" geometric space
- semantic propositions (descriptive information)
- a propositional calculus or algebra
- no analog geometric configuration information

o natural languages (linguistics)
- "near", "far"
- "on top of", "below"
- "front", "back", "left", "right"
- "north", "east", "south", "west"
- "between", "among", "amidst"
- "across", "through", "into", "in"
- frame of reference (relativity)

Any GIS system must deal with at least one of these paradigms; most deal with two or more. For example, a modern topologically based GIS deals with at least four of the above types, with their associated morphisms:

- o the topology structure

- o the underlying Euclidean geometric structure used for storage, simplifying interpolation, intersection and orientation calculations

- o the various projections, and/or elevation models. (Gaussian spaces, inheriting their curvature tensor from the embedding of the ellipsoid or elevation surface in a Euclidean 3-space

- o the unified spatial and attribute query language, a propositional space

The topological-to-propositional morphism would be used to translate some query processing based upon topological relations. For example, "find all roads that cross rivers might be effectively translated into "find all nodes common to these two sets of geometric objects" (the attribute portion of the query could be parsed out and solve in a completely propositional process). Metric queries would be translated to the Gaussian ellipsoid model as statements such as "find the length of this curve" or "find the area of this portion of the surface of the ellipsoid." If a elevation model is included, then another Gaussian model may be used to "find length (area) of this curve (surface) over the elevations model."

Feature Types

The features or objects with which a model can deal depends on the paradigm (e.g. Gaussian geometry deals with geodesics, curves of locally shortest arc length curves, instead of straight lines). Some fundamental commonalty of concept applies across many of the models, and most of the paradigms deal at least with the following concepts:

- o points, locations or simple 0-dimensional objects
- o curves or simple 1-dimensional objects
- o polygons, areas or simple 2-dimensional objects
- o complex, homogeneous and non-homogeneous collections of any other features (possibly recursive in definition but not in realization)

Some of this commonalty derives from the embedding of the conceptualizations, such as any Euclidean space is Gaussian, both of them are also metric spaces, and all of them are topological spaces. Other commonalty derives from the morphism and often generates what at first may seem like oxymorons, as in "a raster line" (the morphism image of a line in raster space).

The Operator Algebra

The operators that exist within a paradigm can be classified according to the domain of their input and returned value. One of the most common operator type is the Boolean or relational type; those that input two simple objects and return a truth value (either TRUE or FALSE). For example, the proposition "A intersects B" can be thought of as an operator equation "intersect(A,B) = TRUE". As Boolean operators, they can be operated on by the standard Boolean combiners AND, OR, XOR, and NOT. Inferences of spatial reasoning can thus be expressed as equations or propositions in Boolean logic, for example:

if
    "A contained in B" AND "C disjoint from B"
then
    "A disjoint from C"

or in equivalent equation form

(contained_in(A,B) AND disjoint_from(C,B)) OR NOT disjoint_from(A,C) = TRUE

Other operators input simple objects or sets of objects, returning sets of objects as in "which rivers intersect this road?" (inputs a "road" and the set of all "rivers", returns a subset of "rivers"). Others may input objects or sets of objects and return sets of geometry as in "where does this river intersect any road?" (may return a set of points or point objects, nodes in a topological paradigm, if the input objects were represented by curves). Other still may return ordered tuples of objects and geometry as in "which rivers intersect which roads and where do these intersections occur?" (returns ordered triples consisting of a "river", a "road" and a piece of geometric information, such as a node in a topological paradigm).

Of course, these classes of operators are inter-related. Statements concerning these inter-relationships form part of the operator algebra. For example, one could use the relationship between the operators "intersect" and "intersection" to make the following propositional algebra statement (IFF is "if and only if" or propositional equivalence):

intersect(river, road) = TRUE IFF
    intersection(river, road) is not the empty set

Such equations from the operator algebra can be used to define one operator in terms of other more primitive ones or to support systems for spatial inference or reasoning.

Morphisms

The translation properties that define how one paradigm can be mapped onto another are collectively called the "morphism." These morphisms must describe how objects, relations, operators and operator algebras map to one another. A morphism must be defined for each pair of views that coexist within a single GIS.

The simplest case of this occurs in a topological GIS, where the topology is calculated form the input geographic coordinate information. During topological structuring, distinguished points and the intersections of the 1-dimensional input elements are associated to nodes, the resulting connected strings to edges, and the polygons to faces. This establishes the geometry-topology morphism for simple objects. The morphism for features and other complex objects is derived from this basic geometric one, so that area features are mapped to collections of faces, line features are mapped to collections of edges, and point features are mapped to collections of nodes.

With this in mind, the process of a simple spatial query can be interpreted as a sequence of subprocesses, each within a single paradigm, interspersed with the use of morphisms to map from one paradigm to another. For example, beginning with "find all places where roads intersect rivers, report on the location, and place a bridge at those points" begins in a propositional form. Remaining in this form, a list of roads and rivers are obtained. Translating via the morphism to topology, the roads and rivers become lists of edges. Using the topological paradigm, nodes are found that form the ends of these edges. The road-node list is compared to the river-node list for common points (in yet another propositional paradigm, this process is often referred to as a spatial join, due to its similarity with the relational join operator). Each such common node represents a location where a river and a road cross, and mapping to the geometric paradigm, the coordinate location, and orientation of the road at that point are determined (enough for the report requested). Returning with this information to the propositional paradigm, a bridge can be created with this location (associated to the node found) and orientation. Of course most of these morphism shifts are so natural, that implementors seldom realize that they have changed paradigm through the use of a morphism.

The Advantages of the Category Model

The natural shifts from one spatial paradigm to another would at first glance seem to suggest that studying them separately might be of little value. This is misleading for two simple but important reasons.

First is complexity. The combined paradigm is sufficiently complex as to make single-approach research very difficult. A standard algorithmic technique when presented with such a complex problem is "divide and conquer," based on the assumption that it is often easier to attach a set of simpler problems and aggregate their solution, than to solve the more complex one. By separating each of the simple systems from the main body, a set of problems susceptible to straight forward theoretical attack becomes available. In the case of the more mathematically define paradigms (the geometries and topology) there are large, well-developed and fairly complete mathematical theories for them. For the propositional paradigms, both data base management and linguistic approaches seem appropriate.

Second is efficiency. Each of the paradigms result in significantly different data structures, and extremely different algorithms for the solution of the various types of spatial problems. In determining whether of not to support a particular paradigm within an application system, you must decide if the advantages of the paradigm's algorithms outweighs the expense of supporting and maintaining (or calculating) the requisite structures. To make this cost-benefit analyst accurate, you must be able to estimate the cost of maintaining the structures, translation between supported paradigms, and solving homeomorphic problems in the separate systems. For example, supporting real-time topology requires a certain amount of storage overhead for the boundary relation structures, and a processing overhead for maintenance while not supporting it costs heavily in processing time for the repeated calculation of geometric intersection and overlay for spatial analysis, and represents an hidden cost in system flexibility.

Summary

This description has laid out the basic framework for a category theory of spatial representations and relations. Each of the research topics suggested for spatial relations falls neatly into a slot within this general theory. The importance of each topic can be gauged by:

- o how it fills the gaps in the knowledge or understanding for particular paradigms
- o how it builds bridges (morphisms) between the paradigms
- o how useful the paradigms studied are (as measured by its success in solving real problems with efficient algorithms)

A-2: Some Comments on Research Issues

Dr. Jan W. van Roessel
TGS Technology, Inc
EROS Data Center

1. I would like to classify the proposed effort in terms of John Herring's category theory of spatial representations and relations. I think it involves the point-set paradigm of topological and metric space, as well as all the mathematical paradigms that relational database theory is based on. It also involves an area where a large number of paradigms are applicable, as long as they lead to languages that can transform attributes in relational tuples.

2. The point would indeed be to explore the morphisms between the paradigms, such as for example, the relationship between relational joins and Venn diagrams, to fill gaps in our knowledge and to build bridges that allow us to exploit existing theory in either paradigm area that otherwise would lie unused. I believe that these gaps exist because until now we have applied the "divide and conquer" technique, at least as far as attributes and space are concerned, but we have failed to enter into the final "join" phase, which puts the parts together again.

3. I would like to point out that the class of spatial problems that the model would address are of the "provide location based on stated attribute(s)" type, which, at least in natural resources applications, may be the most prevalent and basic type of GIS query. To me, this is much more important than navigational type queries such as "give me places north of the airport."

4. Already there are some interesting questions that can be asked based on an initial general model as proposed. Implementations of overlay processes are usually fairly closed, in that the data base provides screened input to the process, the overlay is performed, and the output is returned to the data base. However, if any language, including a data base language, may serve as "the attribute transformer" then the overlay process could consist of an initial join phase, followed by processing by a general database management system, followed by an "object creation phase." Are there implementations that work this way?

5. If the join phase and the object creation phase are pretty much standard operations, then can standard query languages such as SQL be interpreted in a spatial sense without having to add language extensions? In other words, change the underlying implementation mechanism, rather than change the language. I suspect that this is possible, at least for a certain class of spatial queries, such as location by attributes. How can spatial queries profit by the optimization techniques that have been developed for relational databases?

6. Of course, some of the notions, such as a "spatial join", are not new, and the idea of a general attribute transformer at least in the raster domain has been around since before the invention of the term "GIS". However, these ideas have not been consistently developed; for instance, I don't know of a precise definition for spatial join in the literature.

If anyone is interested in pursuing this particular topic, I would certainly like to collaborate and produce a joint paper.

A-3: Toward an Adaptable Spatial Processing Architecture

Dr. J. Armando Guevara
Environmental Systems Research Institute, Inc.

A geographic information system (GIS) is composed of a set of building blocks termed *geographic information system procedures* (GISPs). A geographic information system procedure is an abstract algorithmic function of a GIS that allows one to select, process, or update elements from a spatial data structure (SDS) and/or a spatial data base. Based on this, a GIS can be defined as a model composed of a set of objects (the spatial data structures) and a set of operators (the GISP) that perform transformations and/or queries on the spatial objects.

The elements modeled by a GIS are generally imbedded in two-dimensional space and in some instances in a "two and one-half" dimensional, or a three-dimensional space. In addition to the the fact that the elements it manipulates are spatially located, the elements themselves possess a set of attributes that can be qualitative or quantitatively defined. These attributes cannot only give a description of the spatial elements, but can also become a time component (changes in time) of the spatial data base. Given this particular nature, GISP must be able to both query/transform both the spatial elements and the attributes associated with those elements.

GISP are categorized to be the primitive operators of a GIS. In this sense GISP can be:

a) SELECTORS - Capture and select spatial data.
b) RECOGNIZERS - Structure and select spatial data.
c) PROCESSORS - Process spatial data.
d) TRANSFORMERS - Output spatial data.

Part of the complexity of designing a GIS and its associated GISP comes from the multiple target applications that can exist for such systems. To control this complexity and maintain its generic nature, a GIS must suffice answers to the following continuity concepts:

1. Functional continuity: the ability for a GIS to have a transparent functional flow of control.

2. Data base continuity: the ability of a GIS to manage huge amounts of data on a distributed system as one logical data base and multi-user access.

3. Data structure continuity: the invisible coexistence of vector, lattice, and raster data structures under one data model.

4. Knowledge continuity: the utilization of artificial intelligence techniques to create schemas for data base model usage and to create application procedures.

5. Human interface continuity: what makes a good GIS interface?

6. Data transfer continuity: the ability of a GIS to exit and transfer data, independent of the hardware platforms.

The above notions, each one, are a complete treatice dealing with digital spatial knowledge, digital spatial representation, digital spatial data structures, and digital spatial algebras. I emphasize the term digital because I feel that, although human cognition of space can give insight into its digital representation, it may not necessarily yield the appropriate answers needed, for example, to robotic perception. How a human finds a path can be drastically different to how an algorithm/heuristic system will navigate and discriminate a set of geometric objects to find its way.

As knowledge has been gained on the behavior of spatial algorithms, a functional categorization (functional breakdown) that does away with functional continuity has emerged. Functional continuity refers to the ability in a GIS to be able to access any data set (or portion thereof, in a seamless data base) and apply operators without the system losing track of the data environment and the history of the operations performed. Functional continuity would allow access to all GISP within one process environment. Although such a system would have tremendous power, it is not without its user interface complications.

The functional categorization introduced gave way to the basic architecture of a GIS: data input, data base management, analysis, and output. Within each category, different means have been created to handle the user interface. Menu and command driven functions have become the main ways of interaction. These functions have a proper protocol to internally deal with the processes. Some are action driven while others are environment driven. Action driven functions produce an immediate feedback to the user (e.g., draw a map). Environment driven functions have a cumulative effect that ends in an action driven function. Action driven functions are easy to explain and use. Environment-driven functions pose a variety of user interface problems.

A functional continuous GIS would be mostly environment driven. Such a system would require knowledge of environment and function tracking procedures. Recognizing the importance of user interaction with a GIS is the concern of the Human Interface Continuity Principle and is key to the life appreciation or depreciation of the system (how easy or complicated it is to learn and use).

Data Model Structures

One of the most important concepts introduced in GIS, that has allowed the user to digitally model spatial relations, has been that of topology. The various data structures introduced to handle geographic data (Morton sequences, Peano curves, quad trees, R-trees, B-trees, etc.) and their operational data definition (vector, raster, lattice) were mechanisms to bridge concepts of space and processes to its implementation.

To achieve a continuous data model in the true perspective of not just spatial continuity but also data integration, the design of a generic GIS must take into account the integration and management of all these data types (data structures). This would allow a system to handle planimetric data, surface data, and imagery data. Additionally, this notion of spatial continuity would hide the physical representation of the model, allowing for multiflexible ways of handling the model.

Spatial Data Models

The ultimate task of a GIS is to model some aspect of a spatial reality. The model should include enough information that would allow its user to obtain answers to queries and to infer situations that otherwise would not be possible. Two types of models can be identified:

a) generic functional models
b) specific derived models

A *generic functional model* (GFM) is a model made of basic spatial primitives: points, lines, and areas. The model holds descriptive data about the primitives but does not know about existing relationships. The model is functionally driven (i.e., any further inference about the data aside from primitive location and basic description is obtained via spatial operators). The GFM is an open model that requires only very basic knowledge about the spatial primitives being stored.

A *specific derived model* (SDM) is a model derived from established relationships among the spatial primitives and a linkage is created among compounded spatial primitives and their descriptive data. The SDM requires a well-understood knowledge of how the GIS is going to be used and what it is going to model.

The relational approach to spatial data handling falls under the GFM category, while the object-oriented approach falls under the SDM. It is important to understand that these two models are not mutually exclusive (i.e., a GFM can be used to support an SDM). However, the absence of an underlying GFM in an SDM raises flexibility and performance issues.

The GFM should have the following characteristics:

a) It should allow for dynamic relationship construction via spatial operators.

b) Compounding of spatial primitives should be done efficiently without restrictions or constraints. The compounding would still yield a (more complex) GFM.

Internally, the GFM follows a similar structure to that described in the Digital Line Graph - Extended (DLG-E) of the US Geological Survey, with the exception that at the lowest level of the model, relationships are not explicitly stored.

The SDM has the following characteristics:

a) Relationships between spatial primitives are pre-established in the model based on behavioral, procedural, and transactional facts. These facts make the SDM schema.

b) Mutations on the spatial primitives should be done efficiently. Mutations such as aggregation (compounding) and disaggregation (uncompounding) would still yield a (more complex or simpler) SDM.

The SDM would be the basic model for object-oriented transactions. Both the GFM and the SDM should allow for the following types of data base queries:

a) *Spatial Context:* given an unambiguous geometric definition, extract from the data base all elements selected by the geometric definition.

b) *Spatial Conditional Context:* given an unambiguous geometric definition and a condition expressed in terms of the stored descriptive data, extract from the data base all elements selected by the geometric definition and that suffice the descriptive condition given.

c) *Descriptive Context:* given a descriptive data element, extract for the data base all elements that match the one given.

d) *Descriptive Conditional Context:* given a descriptive data element and a condition expressed in terms of the given element, extract from the data base all elements selected that suffice the descriptive condition given.

The conjunction of a GFM and an SDM would give the user the ability to perform spatial operations at various levels of complexity and integration. GFM and SDM bring the ability for a GIS to be flexible and schema-independent.

Finally, both the GFM and the SDM should maintain the data base continuity concept (i.e., preserve the notion of a continuous physical space underlying the data model).

Toward an Adaptable Spatial Processing Architecture

A modern GIS is expected to be able to integrate a variety of different data sources; these data sources will be used in many ways and also under a wide range of decision support situations. The nature of separate user views of the same data base accompany a series of (sometimes conflicting) demands to the GIS designer that must somehow be met to guarantee the usefulness and longevity of the system. In synthesis, a GIS is a multidisciplinary tool that must allow for interdisciplinary support. Specialized spatial information systems are not multidisciplinary tools, thus are very restrictive in regards to what can be done with them.

An Adaptable Spatial Processing Architecture (ASPA) is what is needed to meet the demands of both multidisciplinary and specialized applications. ASPA fundamentals are based on a GFM that has a set of functional (GISP) primitives clearly defined that allows the automatic construction of a SDM. ASPA has to be designed, based on the six continuity criteria given above. In this respect, ASPA would be an expert monitor based on a high level language consisting of spatial operators that have definable hierarchical constructs. These spatial operators can be organized following a programmable schema that would allow them to generate the SDM. ASPA would work in conjunction with a data base management system (DBMS). The DBMS would respond to both spatial and nonspatial operators. The heart of ASPA and the DBMS would be a GFM.

The spatial operators and spatial data structures that ASPA are built upon is based on the five basic software engineering principles of modularity, encapsulation, localization, uniformity, and confirmability, applied through the concept of abstraction at the design level of the SDM.

The interactions across the GFM and the SDM will be accompanied by rules governing the inter-relations between them. There are two important rules borrowed from the concept of levels of abstraction. The first concerns resources: each level has resources which it owns exclusively and which other levels are not permitted to access. The second involves the hierarchy: lower levels are not aware of the existence of higher levels and, therefore, may not refer to them in any way. Higher levels may appeal to the external functions of lower levels to perform tasks and also appeal to them to obtain information contained in the resources of the lower levels.

In this respect, the lowest level of abstraction is composed of the GFM, a clearly defined set of spatial operators (selectors, processors, recognizers, transformers) and a DBMS.

Data and System Independence

A GIS must be data and system independent. Multiple functional mappings should be allowed between the GFM, SDM, and any external data transfer operator. Similarly, the levels of abstractions induced in the GISP should allow the GIS to perform identically on different computers with no user intervention when doing the functional mappings.

Conclusion

GIS technology has finally taken off in the eyes of the world; but it really is only the beginning of a great adventure!

As GIS users become more knowledgeable and demanding, the strength and goodness of a design is truly discovered. The notions of continuity presented above are very important issues that need to be covered for a successful design. In my experience, along with the internal algorithmic robustness and data base consistency and integrity, flexibility and user friendliness (magic words) are today the most relevant points to be considered from the outcome of what it is to be an adaptable spatial processing architecture.

We should avoid making the mistake made during the 1970s, when authors entrenched themselves in discussions about whether raster data structures were better than vector structures. None and both were the answer. As we move toward more sophisticated systems and users, we must not lose track of the flexibility geographic information systems must have. GIS are multidisciplinary tools. Fixed schemas will hinder GIS usage.

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