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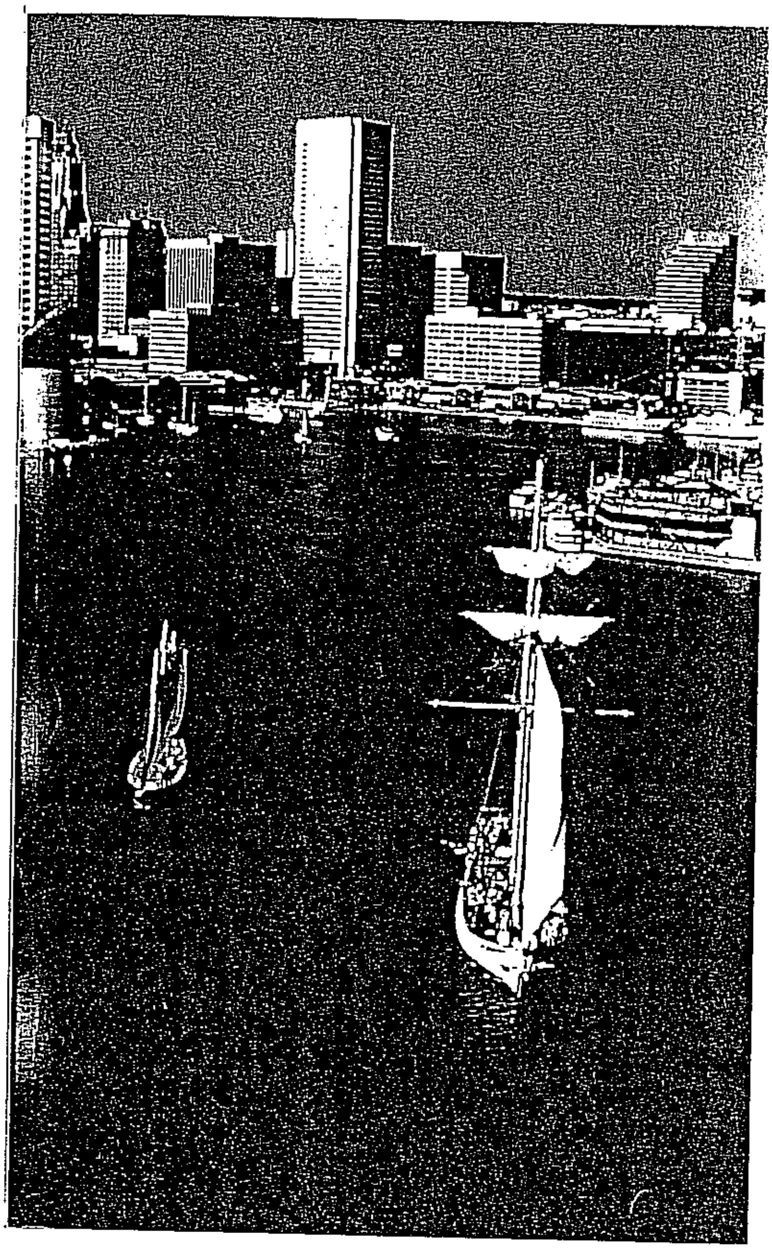

CONCEPTS OF SPACE AND SPATIAL LANGUAGE

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ABSTRACT

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

INTRODUCTION

Spatial relations do not exist in the real world; rather, they exist in minds, to aid in making sense of that world, and in interacting with it. This paper discusses two approaches to the definition of spatial relations: experiential and formal. *Experiential models* are based on sensorimotor and visual experiences with the environment. Since it appears that most people experience the world in similar ways, experiential models of geographic space are expected to have much in common across individuals; spatial properties and relations in experiential models also should conform well with principles of naive (or common-sense) physics. Experiential models of space reveal themselves through spatial reference in natural language and through spatial behavior, either natural or under experimental conditions. On the other hand, *formal models* of geographic space employ mathematical or logical axioms and principles to build formal geometries, topologies, algebras, and logics for representing and manipulating spatial relations and objects. They may bear strong similarities with experiential models because often they have been developed to deal with the same kinds of properties of human observation and experience. For example, 'geometry' is said to have begun as rules and procedures used for land survey in ancient Egypt; Euclid further formalized these principles. Euclidean geometry is closely related to Newtonian (solid-body) physics; however, Newtonian physics itself corresponds closely with naive physics in many (but not all) every-day situations. *Experiential realism*, a philosophical basis for cognitive science advanced by George Lakoff (1987) and Mark Johnson (1987), and discussed recently in a geographic context by Couclelis (1988), is central to the models discussed here.

One of the five high-priority topics for research by the National Center for Geographic Information and Analysis (NCGIA) is "a general theory of spatial relationships" (Abler, 1987, p. 304). Abler goes on to elaborate that the goal is "a coherent, mathematical theory of spatial relationships" (Abler, 1987, p. 306). On the same page, he also states:

> "Fundamental spatial concepts have not been formalized mathematically and elegantly. Cardinal directions are relative concepts, as are ideas basic to geography such as near, far, touching, adjacent, left of, right of, inside, outside, above, below, upon, and beneath."

A "theory of spatial relationships" should not only be mathematically elegant. Its concepts also must correspond with those concepts used by human minds during spatial cognition, spatial reasoning, and spatial behavior; otherwise, it will be of little if any use to geographers, spatial analysts, or geographic information systems (GIS) users. Thus the search for "fundamental spatial concepts" must be conducted in the cognitive sciences before or in parallel with searches in mathematics.

Of course, this search for fundamental spatial concepts as a basis for geographic data structures is not new. More than a decade ago, several papers at the Harvard symposium on data structures for GIS addressed just these issues, and provided a number of approaches (in particular, see Chrisman, 1979; Kuipers, 1979; Sinton, 1979; Youngman, 1979). Now, however, the emergence of cognitive science, which seeks formal representations of how the mind deals with various phenomena, provides a new basis for advancing the topic.

In this paper we expand on the concepts and assertions mentioned above, and propose a strategy for relating various models of geographic space and concepts of fundamental spatial relations. We use spatial language, i.e., the terms in human language that people use to refer to spatial situations, as an important indicator of the major ways in which people conceptualize space. This is in some contrast to the approach used recently by Peuquet (1988), who based her "conceptual synthesis" for representations of geographic space more strongly on models of vision. An important goal of our approach is to identify those spatial concepts that are invariant under groups of transformations; this should contribute substantially to mathematical studies in both cognitive science and geography. This paper is a preliminary report on work in progress by both authors. We hope to reach a more comprehensive understanding of these topics ourselves, but also believe that some of the questions posed here will be of interest to others. Some on the material presented in this paper is taken from drafts of other manuscripts which we plan to publish in the near future.

MODELS OF 'SMALL-SCALE' SPACE

Downs and Stea (1977, p. 197) distinguished perceptual space, studied by psychologists such as Jean Piaget and his colleagues and followers, from "transperceptual" space that geographers deal with and that we are discussing in this paper. They claimed that "the two scales of space are quite distinct" (p 197) in the ways people perceive and think about them. Later in the book, Downs and Stea (p. 199) contrasted the terms "small-scale perceptual space" and "large-scale geographic space." At about the same time, Benjamin Kuipers (1978, p. 129) defined *large-scale space* as "space whose structure cannot be observed from a single viewpoint." The large-scale/ small-scale distinction of Kuipers does not quite correspond to a geographic/ non-geographic contrast, since as Kuipers pointed out, a high mountain viewpoint or an aircraft permits direct visual perception of fairly large areas. Nevertheless, we will follow Kuipers, and use the term *large-scale space* as he defined it, and *small-scale space* to refer to subsets of space which are visible from a single point.

Our cognitive models of small-scale space develop from direct perceptions of our everyday world, dominated by a combination of visual inputs and the interactions of our bodies with the objects in that space. People are very good at processing the visual field, and at interpreting observed sequences of two-dimensional images to be views of objects in a three-dimensional space; in fact, it has been claimed that "the visual system attempts to interpret all stimulation reaching the eyes as if it were reflected from a scene in three dimensions" (Haber and Wilkinson, 1982, p. 25). Michael Crighton describes the relation between visual inputs and the geometry of small-scale space: "When you move inside a space, you must consciously be registering the distortions of the shapes, the moving walls, and corners. Only you don't interpret these as changes in the room itself, but use them as more accurate cues to orient yourself in the space" (Minsky, 1986, p. 256).

As noted above, bodily (sensorimotor) experiences with small-scale space also play a key role in the ways we build our mental models of such spaces. Lakoff and Johnson (Lakoff and Johnson, 1980; Lakoff, 1987; Johnson, 1987) claim that our spatial concepts for small-scale space largely are projected from human-body space. The ways in which the body interacts with objects allow us to recognize 'basic-level' objects such as 'chairs' by the age of about two years (see Rosch, 1973); many spatial-relational words are derived from body parts (for a recent review, see Svorou, 1988).

People also build cognitive models of the way familiar objects behave (react to forces) in small-scale space. The field known as *naive physics* (sometimes 'common-sense physics') deals with the ways in which people typically *think* that physical objects behave. For example, many people not trained in formal physics think that, when a person drops a ball while walking, the ball will fall straight down (McClosky, 1983). In an experiment described by McClosky (1983, p. 125), 80% of college student with no physics training, and 27% of those who had completed at least one physics course dropped a golf ball directly over the target. Of course, according to formal physics, the ball retains a forward motion component, falls in a parabola, and must be dropped before the hand is directly over a target in order to hit that target. Naive physics has associated with it concepts of distance, direction, connectivity, continuity, etc., which might be termed a 'naive geometry'.

Perception of the physics of everyday objects, together with our own bodily structures, also influences the way we perceive and label the structure of space. Gravity is so pervasive that the up-down axis is obviously the most *salient*, or most important to human perception and cognition. The horizontal plane, perpendicular to this vertical axis, is less clearly differentiated in the environment. However, for humans, the front-back contrast, while less salient than up-down, is considerably more salient than left-right. This observation, discussed by Freeman (1975) and many others, probably arises due to the fact that humans and most other animals show bilateral symmetry for external and most internal components. This salience ordering of the three dimensions of everyday space (up-down >> forward-back >> left-right), and the fact that the latter distinction is necessarily egocentric, is important to the models discussed later in this paper.

Introduction of concepts of measurement, mathematics, and science, especially during the time of the classic Greek philosophers, required that geometry and physics be formalized. Schoolbooks tell us that plane geometry was first formalized in Egypt to allow for land-ownership boundaries (the cadastre) to be re-established after the annual floods of the Nile. Abstraction of this practical formalization into a set of axioms is often credited to Euclid. Euclidean geometry conforms by and large to the naive geometry which we observe in our everyday lives. Current school curricula instill upon the pupil the idea that Euclidean geometry is the only 'correct' geometry.

A formal theory of physics proved more elusive, and Aristotelean physics is known to be fundamentally flawed (see Di Sessa, 1982, for a discussion of Aristotelean, Newtonian, and naive physics). The formal physics which corresponds closely to the behavior of everyday objects in small-scale space is usually attributed to Sir Isaac Newton. Newtonian (solid-body) physics is consistent with Euclidean geometry, and corresponds with naive physics well enough that people who 'believe in' Newtonian physics can deal with everyday objects as if the objects were governed by its 'Laws'. (For discussions of naive physics, see McClosky, 1983, or Hobbs and Moore, 1985.) Newtonian physics conforms closely with observable reality, while at the same time is a highly abstract, formal system which is extremely useful in engineering and scientific applications, where it can be used to build models and to predict accurately the behavior of mechanical systems.

MODELS OF 'LARGE-SCALE' ('GEOGRAPHIC') SPACE

The region of space that we can experience bodily at any moment is limited to a few cubic meters; the region we can experience visually usually is larger and much more variable, but still generally is much smaller than the combined extent of all the spaces that we experience during the course of a day's activities. Benjamin Kuipers' model of spatial knowledge acquisition (Kuipers, 1978, 1983a, 1983b) begins from a sensorimotor experiential base. As we move through large-scale space, we see a sequence of views (a 'view' is defined as the sum total of all sensory inputs when at a point and oriented in a particular way, but for most people, the 'views' are dominated by visual inputs). With some views, we associate actions; some actions form part of the navigation or way-finding process, and other actions relate to other activities. Kuipers' TOUR model (implemented in LISP) uses as input ordered sequences of view-action (V->A) pairs. The routes form a 'spaghetti' of familiar paths, which constitute procedures for getting from one place to another. (Interestingly, although we first used this metaphor because of the frequent use of the term 'spaghetti files' in digital cartography, Bruce Chatwin [1988, p. 16] explicitly used the 'spaghetti' metaphor in describing the models of geographic space that are central to Australian aboriginals' myths and traditions; "One should perhaps visualize the Songlines as a spaghetti of Iliads and Odysseys, writhing this way and that, in which every 'episode' was readable in terms of geology.") Many other mobile organisms presumably have similar internal representations of large-scale space. Note that this kind of spatial knowledge is termed 'topological' by Piaget and his followers (Piaget and Inhelder, 1956), and 'procedural' by Thorndyke and Hayes-Roth (1982) and by Mark and McGranaghan (1986).

Kuipers (1978, 1983a, 1983b) noted that, as people find their way along various paths, they may recognize that the paths have some points ('places') in common. This allows them to use inference rules to build network models of places and connections, paths and barriers, in large-scale space. Such a cognitive model of large-scale space allows route-planning to novel destinations, or the planning of alternate routes when habitual paths are blocked. (Incidentally, such adaptive route-planning appears to not be restricted to human beings; Tolman (1948) discussed experiments in which laboratory rats were observed to use alternate paths when the usual ones were blocked by barriers.) Paths may have associated with them properties such as length in miles, kilometers, or blocks, or expected traversal times, but global geometric properties, such as coordinate locations, straight line ('as the crow flies') directions and distances between points, etc., often are weakly defined, inaccurate, or are absent from the model. Such properties of some cognitive models of large scale space were noted very early by Trowbridge (1913).

In Kuipers' TOUR model, spatial inference rules allow the model to be refined more and more, as more and more (V->A)-pair sequences are learned and assimilated, until a 'geometrically-correct' model of large-scale space is built up. However, it seems that, for many people, such a two-dimensional Euclidean (cartesian) model of large-scale space is never built from experience alone, or at least that i takes a very long time. Mark and McGranaghan (1986, p. 402) felt that "access to graphic, metrically-correct maps almost certainly plays a key role" in the development of a cartesian cognitive model of geographic space. Such a conjecture is implicit in the findings of Thorndyke and Hayes-Roth (1982), and is supported by recent experiments by Lloyd (1988).

In his presentation at Auto Carto 8, Matthew McGranaghan stated that the power of maps comes from the fact that they represent space with space. In fact, maps represents *large-scale* (geographic) space in a *small-scale* space on a piece of paper or a computer screen, allowing us to 'vicariously experience' the geometry of the large-scale space in a 'familiar' way, that is, in the way we experience small-scale space (such as objects on a desk-top) in our everyday lives. Thus the map allows us to extend Euclidean geometry (which is a very good approximation to the 'true' or 'objective' geometry of small-scale space) outward onto large-scale space, to be used as a basis for certain forms of spatial inference, reasoning, and decision-making.

There is little doubt that maps do allow people to extend a model of the geometry of small-scale space outward to large-scale space; however, this may be judged to be 'good' or 'bad', depending on beliefs about 'truth', or on the uses to which the model of large-scale space is to be put. If one believes that Euclidean geometry is also the 'true' or 'objective' geometry of large-scale space, then the map is a very valuable tool, since it allows us to grasp this 'truth' and use it. With a map in hand, or with a map-based cognitive model of space, we can plan routes and perform other spatial inference using the familiar Euclidean model. However, if the 'true' geometry of large-scale space is believed to be the type or level of cognitive map which is acquired only through direct experience (and such experiential cognitive models almost certainly are not Euclidean), then the fact that maps extend small-scale geometric principles to large-scale space means that they are an 'incorrect' model for large-scale space. As early as 1980, Drew McDermott argued that the topological view of space inherent in Kuipers' model is not a good theoretical basis for spatial reasoning (McDermott, 1980, p. 246). As an alternative, McDermott proposed a theory of "metric spatial inference" based on a "fuzzy map" geometry, of positional uncertainty within a Euclidean coordinate framework. Later, McDermott and Davis (1984, p. 107) proposed an intermediate or hybrid model, in which the cognitive map might "consist of an assertional data base for topological information and a 'fuzzy map' for the metric information."

WHAT IS THE 'OBJECTIVE' GEOMETRY OF GEOGRAPHIC (LARGE-SCALE) SPACE?

What is meant by 'correct' geometry? We begin with the assumption that the 'real world' exists, and that it has 'objective' properties. This is an assumption and not a 'fact', since the human mind has no 'direct' access to the real world, but only is aware of what the senses appear to report. Since the decision to adopt a particular definition of objectivity is itself subjective, Hillary Putnam has shown that a paradigm of complete objectivity is internally inconsistent (see discussion in Lakoff, 1986, pp. 229-259). Nevertheless, *experiential realism*, proposed by Lakoff and Johnson (1980) under the term *experientialism*, is based on the idea that there *is* a real world, which has consistent properties, so that when people interact with that world, their mental experiences are very similar (see Lakoff, 1987, especially pp. 265-268). If we adopted *reproduceability in measurement* as an essential part of our definition of 'objective' reality, then the 'correct' geometry is the one which best supports reproducible measurement of positions in real-world geographic space, namely, 'the' geometry of surveying. At scales ranging from planet earth to the human body, Euclidean geometry and Newtonian physics seem quite adequate. The fact that Euclidean geometry breaks down at certain time, space, or velocity scales, and that Einstein's theory of relativity required new geometries, thus re-orienting the cutting edge of academic geometry, is of little relevance to geography and surveying.

Even if Euclidean geometry is 'correct' in the narrow ('objective') sense stated above, it still does not seem to represent large-scale space the way most people think about it, or the way in which they reason while way-finding in a familiar large-scale space. However, map-based reasoning, that is, spatial reasoning based on a Euclidean two-dimensional geometry, may well be the best available form of spatial reasoning for navigation and other spatial tasks when those tasks must be performed *in an unfamiliar environment*. The high annual sales figures for road maps and road atlases support the idea that most non-technical people believe that maps are, if not optimal, at least very good in this regard.

It is not far wrong to view our planet as a spheroidal solid body in Euclidean 3-space; geodesy has established the shape of that body, and of the geoid. The surface of the earth is essentially a 2-dimensional manifold stretching over the surface of that geoid; position can be denoted as two angles (latitude and longitude), and elevation above 'sea-level' at any point may be defined as the height above that geoid. Map projections allow us to transform from one 2-dimensional surface (over the spheroid) to another (a cartesian plane) in ways which control the geometric distortions tha necessarily result.

For 'sufficiently-small' regions of the planet (say, up to about the siz of the 48 contiguous United States, or Australia), the curvature of th planet can more or less be ignored; map projections exist which shov almost no distortion of areas, angles, or distances over regions of tha size or smaller. For example, Lambert's conformal conic projectio with standard parallels at 33 and 45 degrees north provides correc angles (by definition), and a maximum scale-variation of one-half o one percent between latitudes 30.5 and 47.5 over the 48 contiguou United States (Snyder, 1982). Thus it is 'reasonable' to treat the cartesian coordinates of Lambert's projection as the basis for a Euclidean view of the geographical geometry of the contiguous Unitec States, or of subregions thereof.

Measurement is often considered to be the only way to 'see' space in an objective way (because it is obviously reproducible). However, it also is possible to define 'correct' in a way which does not to rely on the concept of measurement. People usually experience space not by measurements, but rather by observing results of processes that are related to space. An every-day examples for such a process is that time is consumed by physical movement in space, and then that there are other 'costs' of travel. This approach also is applied to observations of how social systems behave in space, including the perception and cognition of regions and urban centers.

This experience with processes that are influenced by other properties of geographic space creates another, indirect concept of space that is found among neither the concepts learned through navigation in large-scale space nor through the utilization of concepts from small-scale space to organize spatial precepts. To a degree that these processes avail themselves to 'objective' measurement, the spatial properties they react to can be indirectly observed and deduced. On a conceptual level, the difficult task is to combine the multiple, conflicting concepts human beings use and understand in their interaction, and to model how they influence specific behavior. Geography deals with many of these spatial processes, and thus geography and geographers can play a key role in discovering the spatial properties influencing these processes; this may in turn help to understand human spatial cognition.

SPATIAL RELATIONS

John Freeman (1975) provided an important and early review paper on formal representation of spatial relations. Freeman proposed that the following form a complete set of primitive spatial relations for elements in a (2D) picture, a view of a (3D) small-scale space: 1. left of; 2. right of; 3. beside (alongside, next to); 4. above (over, higher than, on to of); 5. below (under, underneath, lower than); 6. behind (in back of); 7. in front of; 8. near (close to, next to); 9. far; 10. touching; 11. between; 12. inside (within); and 13. outside. Note that this is not a *minimal* set of relations, since some can be defined as combinations of some of the others.

Freeman's list is very similar to the list of terms presented by Abler (1987, p. 306) and quoted in the introduction to this paper. The cardinal directions can be added to Freeman's list through the addition of one more axiom. If we associate 'north' with 'up', then 'south=down', 'west=left', and 'east=right' can follow deductively. Peuquet and Zhan (1987) extended Freeman's (1975) relation set in exactly this way, including the cardinal directions as spatial relations without comment, and substituted 'north' for 'above' and 'south' for 'below' in the example they drew from Freeman's paper (Peuquet and Zhan, 1987, p. 66). Note that the 'north=up' axiom is quite arbitrary. Indeed, the etymology of the Indo-European root for the word 'north' is based on 'left' (Svorou, 1988); this relation results from an earlier 'east=forward' convention, and world maps in Medieval times were presented with an east up *orient*ation (orient=east).

It is useful in such a system to maintain a strong society-wide tradition of keeping the same cardinal direction 'up' in both mapping and speech; although there are many local exceptions (usually based on locally salient physical gradients; see Mark, Svorou, and Zubin, in press), using 'up' to refer to directions other than north is considered to be 'wrong' by many English-speakers with little or no formal cartographic or geographic training. Note that in this model, the north-south geographic axis is 'bound' to the most salient directional axis (up-down) of small-scale space, and (east-west) is bound to the least salient of these (left-right). Could this account for the tendency for some people to confuse east-west more readily than north-south?

Some cultural and linguistic groups, including the Hawaiians and many other island dwellers, use a radial coordinate system for referencing in large-scale space (see Mark and others, in press). This uses the 'inside-outside' dichotomy of the container metaphor (see Lakoff, 1987) for one spatial dimension, and 'toward some landmark' (spatial action, rather than relation) as the other. Other island peoples use similar spatial reference frames (see Haugen, 1957, for a discussion of this for Iceland).

REFERENCE FRAMES

Mark and others (in press) have noted the importance of reference frames in the generation of spatial language. For example, a building such as a church has around it a region or ground. The structure of the church and the ways people interact with it give the church a 'front', a 'back', sides, *et cetera.* Then, these parts project outward onto adjacent regions of the ground, leading to the division of that ground into subregions: the subregion adjacent to the back of the church can be referred to as 'behind the church', and so on. The church and its region provide a reference frame for spatial language comprehension and generation. McDermott's (1980) approach to spatial inference based on fuzzy maps also uses reference frames as a central concept:

> "All of our solutions revolve around keeping track of the *fuzzy coordinates* of objects in various *frames of reference.* That is, to store metric facts about objects, the system tries to find, for each object, the ranges in which qualities like its X and Y coordinates, orientation and dimensions lie, with respect to convenient coordinate systems. The set of all the frames and coordinates is called a *fuzzy map.* We represent shapes as prototypes plus modifications." (McDermott, 1980, p. 246).

If the model get new facts that do not reduce uncertainty, they add features to the model. McDermott gives as an example within the Yale University campus database "the orientation of Sterling Library is the same as the orientation of Becton Library". This adds to the database a new reference frame F, within which (ORIENT STERLING) = (ORIENT BECTON) = 0.0. Then the frame F is itself a new object, with orientation completely fuzzy (0, 2Pi) with respect to other features of the Yale campus.

> "Every object can serve as a frame of reference, and every frame of reference can be considered an object, with a position, orientation, and scale" [within some parent frame of reference]. (McDermott, 1980, p. 247).

In McDermott's model, the nested frames form a tree, which can be rearranged as new facts are added. Cognitive hierarchies of reference frames may not be so simple, and may be networks with loops, multiple hierarchies, *et cetera.*

McDermott has used this as a basis for spatial inference, and for building within the machine a 'cognitive map' (see also McDermott and Davis, 1984). However, as noted above, reference frames form an important basis for the interpretation and generation of spatial language. Furthermore, Roger Downs has suggested that the concept of spatial hierarchy is of critical importance to spatial knowledge acquisition (see Downs' section in Mark, 1988, pp. 5-6). Inference based on hierarchy appears to be very important in much of everyday spatial decision making, and also 'accounts for' the surprise that Reno Nevada is west of San Diego, or that Atlanta is closer to Chicago than it is to Miami. Stewart Fotheringham (personal communication, 1988) is examining residential choice in this context.

THE RELATION 'NEAR'

The word 'near' embodies a fundamental spatial relationship that applies to object pairs in geographic as well as in other spaces. It is among both Freeman's (1975) and Abler's (1987) lists of fundamental spatial relations. Robinson and his co-workers (Robinson and other, 1985, 1986; Robinson and Wong, 1987) have studied the meaning of 'near' from the point of view of fuzzy sets.

Mark Johnson recognizes the importance of 'near' in his discussion of how image schemata, and in particular the center-periphery schema, constrain meaning, understanding, and rationality:

> "Given a center and a periphery we will experience the NEAR-FAR schema as stretching out along our perceptual or conceptual perspective. What is considered near will depend upon the context, but, once that is established, a SCALE is defined for determining relative nearness to the center." (Johnson, 1987, p. 125) .

Mark and others (in press) also recognized the scale-dependant nature of the meaning of 'near'. As an example, the statements: "Santa Barbara is near Los Angeles", "My house is near the University", and "My barbecue is near my swimming pool", all sound reasonable, although the ranges of inter-object distances involved are clearly very different. How is it that the listener or the reader 'knows' what the above assertions mean? In fact, Robinson's results show that even when context, object class, and universe are held constant, there still are individual variations in the meaning of 'near.'

Prototypes form an important part of Lakoff and Johnson's "experiential realism" model of cognition (Lakoff, 1987; Johnson, 1987). As an example given by Lakoff (1987), a 'small galaxy' is not an object in the intersection of 'the set of all galaxies' and 'the set of small things'; we know that the phrase means, "of the sizes that galaxies come in, this particular one is smaller than most." A set-theoretic model, even a fuzzy set model, would have trouble representing the fact that a 'small galaxy' is many orders of magnitude larger than a 'large mouse'. Here, we propose the conjecture that 'near' is a similar concept, and that it takes its meaning from prototypical distances *or interactions* between the kinds of objects in the statement. If this is correct, the problem of determining the meaning of 'near' must begin by determining, from the kinds of objects involved and other aspects of context, what the appropriate prototype is. This is a research topic of high priority.

For someone who knows the 'driving' culture of southern California, the context for "Santa Barbara is near Los Angeles" is inter-city travel by private automobile, using freeways or other highways (with speed limits of around 90 km/hour). The sentence "Santa Barbara is near Los Angeles" might easily be misunderstood by someone from outside North America who has never owned a car. If the listener knows that the speaker works at 'the University', then the context for "My house is near the University" probably lies in what geographers call 'journey-to-work', whereas the context for "My barbecue is near my swimming pool" lies in typical layouts of back yard furniture and appliances. Note that prototypes for the first two situations will be based primarily on spatial interaction; only the last situation has a more static prototype.

The 'near' relation is considered especially critical because it is implicit in many other spatial relations. For example, consider the question of how close together two objects must be in order that the expression "a is in front of b" makes sense. If someone states: "Your bicycle is in front of the house", you would not expect it to be 7 kilometers from the house, even if a straight line from the bicycle to the house meets the front of the house at right angles. In at least most cases, it seems that "A is in front of B" means something like "'A is in front of B' *and* 'A is near B'".

TOWARD A GEOMETRY OF LANGUAGE

It is clear that cognitive models of small-scale and large-scale space are related to the language that people use to describe and communicate about such spaces. How shall these research areas be linked in formal models? We propose that the development of a 'geometry of language' would be a major step in the direction of such an integration.

> After the invention of non-Euclidian geometry, the term geometry needed a new definition, that would include study areas such as 'graph theory' and other more general, but somewhat geometrical topics. Felix Klein [Klein-Erlanger] defines geometry as the science concerned with properties of figures which are invariant under a group of transformations. Transformation is here understood as a mapping of the space

> onto itself, thus including not only the familiar transformations such as translation and rotation but also many others.
>
> Let us first explore this very general definition informally. Assume a space and a figure (i.e. a subset of the space) in it. The notion of space here is more primitive than the one used previously [in Frank 1988] (otherwise we would be caught in a circular definition). It is essentially a finite or infinite collection of discernable objects (typically the points in the space) together with a notion of 'neighborhood'. Then, geometry deals with properties of these figures (eg. lengths of lines, connections between points) which remain unchanged under a class of transformations (eg. translations, rotations, map projections). Each group of transformation defines another set of geometric properties (distance, angle, area). This notion seems to capture more of what people understand by 'geometry' than is included in classical Euclidian geometry with its points and line. [adapted from Frank 1988].

Couclelis and Gale (1986) also have discussed spatial concepts from a basis of algebraic group theory.

As noted above, a geometry may be defined as "properties which remain invariant under a group of transformations". Thus, we might ask: "Is there a geometry of natural language?" That is, are there properties of the relations between spatial language and the real world which remain unchanged by certain geometric transformations? If so, what are the words or phrases, and what are the transformations? Containment is invariant under many transformations: "the building is inside the fence", "Buffalo is in New York state", and "his grave is in the mission cemetery" will remain true under a very wide range of spatial transformations. However, the statement: "The cemetery is north of the church" will be true if the church-cemetery pair is translated across geographic space, but will not be true after a rotation of 90 degrees. However, the similar statement: "The cemetery is *behind* the church" remains true under both translation and rotation, as long as the transformation is applied to a region including both objects.

Here we again see the critical nature of reference frames. Spatial language of the form "A is behind B" is invariant under a rotation *if and only if the reference frame rotates with the referent.* The cardinal directions are abstract and fixed with respect to the planet; we already ignore the orbiting, rotating, and other astronomical motions of the Earth. Thus, since the astronomical reference frame is never rotated, expressions "A is north of B" would not be invariant under large rotations of the region including both A and B. Since "the cemetery" would almost always fall within the same ground a reference frame as "the church", it thus would rotate with it.

A different and interesting case would be the radial reference fran common to Hawaii and many other oceanic islands, alreac mentioned above. If the entire island were rotated, the meaning the language would not change, but if a town or shopping center rotated, the spatial language probably would no longer apply. In th case, since the reference frame is radial, a sufficiently larg translation of a subregion of the island, with no rotation, could als make the utterance untrue. Reference frames will play a critical ro in the development of any geometry of spatial language.

SUMMARY

Development of a comprehensive model of spatial relations an properties is important to the future of systems for geographi information and analysis., and also to cognitive science and t behavioral geography. This paper first reviewed concepts of space A critical distinction is between small-scale spaces, whose geometr can be directly perceived through vision and other senses, and large-scale space, which can be perceived only in relatively small parts Fundamental terms for spatial relations often are based on concept from small-scale space, and are metaphorically extended to large-scale (geographic) space. Thus, terms and concepts for the spatial relations among the objects in a picture can form an appropriate core for spatial language. Spatial relations at a geographic scale are formed either by extension of these terms, or by addition of a small set of additional principles (for example, letting "north" equal "up"). Reference frames form an important basis both for spatial language and for spatial reasoning. Prototypes also are important, and probably play a central role in the way we determine the geometrical meaning of spatial relations such as 'near'. Finally, we set as a short term but important goal a search for geometries of spatial language. This search will attempt to define those properties of particular instances of spatial reference in natural language which remain invariant under groups of transformations. This could form the basis both for aspects of geographic data structures and for the understanding and generation of spatial language itself.

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