Scale and Detail in the Cognition of Geographic Information

Report on a Varenius Specialist Meeting
Santa Barbara, CA — May 14–16, 1998

by Daniel R. Montello and Reginald G. Golledge

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I. Executive Summary

A. Introduction

A 3-day Workshop entitled "Scale and Detail in the Cognition of Geographic Information" was held in Santa Barbara, California, on May 14-16, 1998. This Workshop was sponsored by Project Varenius of the National Center for Geographic Information and Analysis (NCGIA). It is one of the three Varenius Workshops organized by the "Cognitive Models of Geographic Space" Panel, taking place in 1998 and 1999. Reginald G. Golledge and Daniel R. Montello of the Department of Geography, University of California at Santa Barbara, were Co-Leaders of the Workshop. In addition to the Co-Leaders, the Core Planning Committee, responsible for generating issues for the Workshop and selecting participants, included Christian Freksa, Department of Computer Science, University of Hamburg; Michael Goodchild, Department of Geography, University of California, Santa Barbara; Timothy P. McNamara, Department of Psychology, Vanderbilt University; Stan Openshaw, School of Geography, University of Leeds; and M. Jeanne Sholl, Department of Psychology, Boston College.

B. Topic of Workshop

The Workshop focused on research issues concerning the cognition of scale in geographic information, and concerning scale in the cognition of geographic information. The original Call for Participation described the meeting as follows:

> Scale is one of the most fundamental yet poorly understood and confusing concepts underlying research involving geographic information. The term "scale" has multiple referents, including absolute size, relative size, resolution, granularity, and detail. This initiative focuses on explicating the multiple referents of scale and determining their consequences for thinking and decision-making involving geographic information. An emphasis will be placed on cognitive aspects of the scale problem as a complement to the traditional geographic and cartographic emphasis on scale in external representations. Basic questions to be pursued include: How do laypersons and experts conceptualize scale and scale-related phenomena, particularly given the multiple partially-related referents of the term? Do various geographic structures and processes come into existence at particular scales, and if so, how is this understood by users and consumers of geographic information? In what ways do laypersons and experts believe that phenomena are scale-independent or scale-dependent? What role does scale play in traditional arguments about form versus process? What are the difficulties inherent in communicating issues of scale, and what are more or less effective ways of accurately representing information about scale? Geographic information systems currently allow representing phenomena at multiple scales, and

innovations in scale representation are constantly being developed. However, system developers do not pay much attention to issues of how scale communication impedes or facilitates valid communication of geographic phenomena; in particular, there is very little systematic research available to guide the development of such systems. As society makes the transition to the digital environment, associated metaphors for scale and scale transitions are likely to change as well. Map scale or representative fraction, the metric for scale in the traditional cartographic world, has no well-defined meaning in a digital world of seamless perspectives in which the user is free to zoom in or out at will. Can we identify the fundamental, invariant aspects of the concept of scale that survive the transition to the digital world? Can we identify their mappings to the concepts and metaphors currently used in naive and expert geography?

In order to create an initial direction for the Workshop discussions, several "Central Research Issues" were identified in the Call:

1. Difficulty of comprehending scale translations on maps and other representations.
   - single static view, multiple views (zooming in-out).
   - temporal scale in animations.
   - can virtual environments help overcome scale translation problem?
2. Psychological scale classes:
   - what is the evidence for their existence/nonexistence?
   - what is the role of orientation-specificity/flexibility?
   - are they related to a perceptual-cognitive shift?
   - are there specific cognitive processes linked to specific scale classes?
   - does knowledge precision vary with scale classes?
   - what are the implications of such scale classes for the use and interpretation of geographic information?
3. Variations in spatial language as a function of the scale class of geographic phenomena.
4. Effective maximization of presented detail in geographic representations.
5. Basic conceptual structure of scale, size, resolution, and detail as a function of user expertise.
   - how strongly are they correlated? may they be completely independent?
   - do the distinctions exist in a digital environment?
6. How does scale comprehension work in different sensory modalities?
7. Is knowledge derived at multiple scales combined or integrated, and if so, how?
8. Spatial knowledge from CRT vs. desktop VE vs. immersive VE.
9. Pattern extraction as a function of scale.
10. What is the relationship between scale and mental imagery?
11. Are there differences in the implications of scale of length, scale of width, and scale of height with respect to scene processing?

C. Purpose and Structure of Workshop

The purpose of the Workshop was to identify and prioritize a research agenda for the topic. This was achieved via the proposals submitted by applicants to the Workshop, the discussions and interactions at the Workshop, research activities inspired by the Workshop (some of which were fostered by seed grants awarded after the Workshop), and the preparation and dissemination of this Summary Report. The structure of the meeting was a combination of Plenary papers given by members of the Core Planning Committee, small-group "Breakout Sessions" which conducted focused discussions of specific issues, and Plenary Summaries in which the discussions of Breakout Sessions were presented to the entire group.

D. Participation in the Workshop

Potential participants responded to a Call for Participation disseminated to various research communities. The Call asked for the submission of Proposals to Participate in the Workshop, consisting of three parts:

(1) a brief indication of why you want to participate in the meeting, why you are interested, and/or what you would contribute (1 page);
(2) a position statement or research abstract, describing a particular element of or perspective on the topic (3 pages); and
(3) a brief curriculum vitae with up to five (5) selected publications most relevant to the topic (1 page).

All submissions were reviewed by members of the Core Planning Committee for relevance, quality, and originality. Out of 37 potential participants who submitted proposals, 27 were invited to attend the Workshop. A few of those invited did not attend the meeting. Also, Core Planning Group members and Cognitive Panel members were invited to attend. In total, there were 32 participants at the Workshop. Along with the Core Planning Committee, all of whom attended, the list of participants and their addresses are given in Section V. Eleven graduate students from UCSB also participated, and assisted as raporteurs and drivers. Project Varenius provided financial support for lodging, food, and travel to the Workshop.

E. Schedule of Workshop Activities

THURSDAY - May 14:

8:45-9:20am Golledge "Procedures & Charge, Topic Overview"
9:20-9:50am Montello "Thinking of Scale; The Scale of Thought"
10:10-10:30am Openshaw "Optimizing Scale"
1:30-1:50pm Sholl "Are There Different Psychological Scale Classes?"
2:00-3:30pm Breakout Sessions #1

1. Cognitive Scale Classes
2. Communicating and Representing Scale and Scale Changes
3. Aggregation and Scale in Spatial Analysis
4. Understanding Scale and Scale Changes by Subpopulations (e.g., disabled, experts-novices, cultures)

4:00-5:00pm Summary Breakout Sessions #1

FRIDAY - May 15:

8:30-8:50am Goodchild "Scale, Resolution, Process"
9:15-10:40am Breakout Sessions #2
1. Spatial Language and Scale
2. Children and Scale
3. Scale in Virtual Worlds and Cyberspace
4. Reference and Coordinate Systems
11:00-12:00pm Summary Breakout Sessions #2
1:30-1:50pm Freksa "Scale and Detail: A Representation-Theoretic Perspective"
2:15-3:30pm Breakout Sessions #3
1. Geographers' vs. Psychologists' Scale Concepts
2. Research Methodologies for Studying Scale
3. Scale in Formal/Computational Modeling
4. Time and Scale (e.g., animations)
4:00-5:00pm Summary Breakout Sessions #3

SATURDAY - May 16:

9:00-9:20am McNamara "Spatial Representation and Scale"
9:45-11:10am Breakout Sessions #4
1. Scale in Action-Perception Pairings
2. Scale in Human vs. Physical Processes
3. Scale in a Digital World
4. Equivalent Realities/Internal and External Representations
1:00-2:00pm Summary Breakout Sessions #4
2:30-4:00pm Plenary Discussion of Research Questions

F. Outcomes of Workshop

In addition to this report, which includes an extensive list of research questions, the Workshop generated collaborations among participants. Seed grants for collaborative research were awarded to four groups of participants. At least two external proposals have been submitted as a result of these seed grants already, and we are aware of at least two others in preparation. The Workshop attracted several renowned researchers to the Varenius research community that have subsequently participated in other Project activities. A manuscript summarizing some of the results from the Workshop is in preparation by the Co-Leaders and will be submitted for journal publication. In addition to the interdisciplinary interactions facilitated by the Workshop, we also believe the experience for participating graduate students from UCSB is an important outcome of the Workshop.

G. Overview of Report

This report consists of six sections. After this Executive Summary, the report contains summaries of the introductory Plenary talks by Golledge and Montello, and the Plenary papers by members of the Core Planning Committee. Following that are summaries of the Breakout Sessions. That is followed by a list of research questions that arose from the meeting, particularly the final extended Plenary discussion on the last day. The report concludes with a list of Workshop participants and our acknowledgments.

Breakout summaries are based on transcriptions from the tape recorded sessions, and recordings and notes from the summary reports given in Plenary sessions. There is thus a detailed record of most of the sessions, which are summarized and condensed in this report. These summaries reflect the dialogues that occurred during the breakout sessions, the reports given in Plenary, and comments and dialogue that occurred during the Plenary summaries. A couple sessions were not recorded in detail or experienced technical difficulties. These sessions are unfortunately summarized in much less detail. Finally, the report also reflects feedback from meeting participants, who were given a chance to comment on the report before its final version.

II. Plenary Papers

Reg Golledge
"Topic Overview: Scale and Detail in Geography"

After describing the structure and procedures of the meeting, Golledge spoke about the work of the Finnish geographer Granö in his 1929 book "Pure Geography" (recently published in English). He argued that geography should be defined in terms of what humans can perceive in the environment. He distinguished between "proximic" and "landscape" scales of analysis. "Proximic scale" was defined as covering the area from an observer to a "boundary" approximately 20 meters from the viewer. Within this area, phenomena were perceived as three-dimensional objects. Beyond 20 meters there was the "landscape," which extended from the 20-meter boundary to the horizon and was viewed as a two-dimensional feature. On a flat plain, assuming an eye level of 1.5 meters, the horizon would be 4.7 kilometers away. He also suggested a difference between "open" landscapes (obliquely viewed and containing part of the sky) and "closed" landscapes (a bird's-eye downward view containing no parts of the sky).

Granö made a significant decision, arguing that "image" and "recall" were not part of the geographic experience because they could be "distorted in too many ways." Thus he argued for a "pure geography" -- a geography of the perceptual domain, which of course covered only a very specific scale. This suggests the question: Is there some "magic" scale in the spatial domain at which cognitive processes (e.g., as opposed to visual perceptual processes) suddenly become dominant?

There are few direct cognitive comparisons of small- and large-scale patterns, although relevant research can be found in the broader literature on cognitive mapping at both of these scales. There appear to be both commonalities and differences in cognitive representations at different scales. One common element is the use of landmarks. When displays of any scale are viewed, or physically experienced, there is a tendency to displace non-referent points in the space towards reference points or landmarks (several references listed: work by Lederman and Taylor, Nelson and Chaiklin, Sadalla et al., Gale, Golledge and Tobler, Golledge and Spector, Presson and Montello, Golledge and Zannaras, McKay and Olshavsky, Golledge et al., Thorndyke and Hayes-Roth). Another similarity in cognitive mapping of large and small-scale space is hierarchical organization (Hirtle and Jonides, McNamara). For example, judgments of the relative position of cities in the U.S. may be determined by inference from the positions of the states in which they lie (Mackie, Stevens and Coupe). Similar effects have been found for large-scale routes that are learned by a simulated walk through an environment as presented on a series of overlapping slides (Allan, Pellegrino and Doherty, Doherty, Gale). For another common effect, judgments of lengths at both large and small scales increase as the number of distinct locations increases (Briggs, Byrne, Thorndyke, Sadalla et al.).

Cognitive representations of small-scale spaces that are visually experienced appear to differ from representations of larger spaces requiring more comprehensive cognitive organization. This tendency is emphasized when the latter are learned from various types of interactions (e.g., walking through the area). In particular, a variety of studies indicate that the representations of space learned form a map display (one type of small-scale stimulus) is specific to the orientation of the map. Thus, responses become more difficult if an observer or test map is oriented differently from the original display (Evans and Pezdek, Levine et al., George). In contrast, when observers learn about space by navigating through it, judgment appear to be less tied to a particular orientation (Evans and Pezdek, Thorndyke and Hayes-Roth). This holds even for blind-folded explorers who consistently navigate a pathway from the same direction throughout learning (Presson and Hazelrigg). It is noteworthy that in the latter study, routes learned by direct view from a vantage point were similarly "orientation independent," which the authors attribute to the direct perceptual involvement during exposure.

Golledge next listed many research questions on scale in cognitive and geographic research, grouped into six lists:

List #1: Different Views of "Scale"

1. What is "geographic" scale? (Mark and Egenhofer, 1997)
2. What are the other scales besides spatial? (temporal, spatio-temporal, operational -- Lam and Quatrocchi)
3. How do they differ?
4. How do we differentiate between "scale" and "resolution"?
5. Are different spatial cognitive processes at work at different scales? Which ones?
6. Are specific cognitive processes more or less suited to the analysis (or processing) of information at different scales? Why? (Loomis and Philbeck)
7. Are experiments in small controlled laboratory settings generalizable to complex real world environmental settings?

List #2: Scale Effects in Perception and Cognition

1. What is the nature of the transformation from perceptual to cognitive domains? What's the precise definition of a spatial boundary between them?
2. Are there identifiable spatial situations in which spatial cognition is not a dominant process?
3. Do some spatial cognitive processes work at some scale but not others?
4. Is spatial cognition scale invariant?
5. Do spatial processes observable at the "tabletop" or laboratory scale differ from the processes observable in the larger (occluded) environment?

List #3: Scale as Threshold

1. Naive geography defines "geographic-scale" and assumes that "scale matters." If this is so, do certain spatial processes suddenly come into existence at some specific scale? Are they not present at micro-levels, larger cartographic scales? (Mark and Egenhofer)
2. Do all spatial processes have an emergence threshold? Or are spatial and geographic processes really scale invariant but ignored as larger and larger cartographic scales (i.e. smaller and smaller areas) are examined?
3. How do we rationalize the different uses of the scale term (e.g. cartography versus natural language)?
4. Is scale more important in the physical domain than in the human?

List #4: Scale and Representation

1. What scales of representation lend themselves most to visualization? To other forms of representation?
2. How does a scale change influence granularity or clarity of data? (aggregation)
3. Does a change in scale involve loss of original structure and emergence of "artificial" structure or patterns? (Hubert and Golledge, Openshaw, Robinson)
4. To what extent is scale at the crux of traditional geographic arguments of form versus process? (Harvey)
5. Does scale change involve changing models?

List #5: Scale and Human Knowledge Acquisition

1. How well do humans comprehend large-scale environments by representing them in summarized (scaled-down) forms?
2. Can we achieve the same accuracy of representation of spatial relations from primary (active) and secondary (passive) information processing?
3. What do humans mean when they use the term "scale" (e.g., cartographic scale vs. common-sense use)? Does spatial knowledge accrue at similar rates and effectiveness at the spatial scales most relevant for haptics? audition? vision? smell?
4. How can technical advances such as virtual displays help examine current questions about scale effects?
5. At what level of representation (or scale) do spatial patterns (or information presented in point, polyline or polygon format) become obscured or evolve into "new" patterns?

List #6: Scale and Information

1. What is the relation between scale and levels of aggregation/disaggregation in the spatial data representation domain? How much information is lost or obscured when "scaled down" representations are produced (e.g., in representing a point pattern, when does "clustered" become "dispersed"?)
2. To what extent do scaled representations introduce artificiality into knowledge of real world phenomena?
3. How much is scale domain-specific? (e.g., is it specific to the visual domain?)
4. Are there changes in process from the micro (near space) environment to the macro (distant) environment that have previously been observed in the visual world and also are observable in the auditory domain?
5. Is there a micro-macro difference in the haptic domain? What about using haptics to learn large-scale environments? Are there process changes equivalent to those suggested in the visual domain?

Dan Montello
"Thinking of Scale; The Scale of Thought"

Montello began by listing some goals for the meeting. These included: (a) expressing the issues involved and describing the scope of the topic, (b) identifying existing research on the topic -- what do we know?, (c) identifying practical implications of the topic (e.g., for GIS), and (d) identifying research questions. He stressed the multidisciplinary nature of the gathering, and his intent to try and make it interdisciplinary. The latter implies multiple disciplines, as does the former, but interdisciplinary implies that the disciplines are interacting and sharing ideas, concepts, and methods via mutually intelligible vocabularies. This would require, in his view, the need for all participants to express their knowledge with patience, to listen and learn, and to think about some problems that were new to the, participants or at least to think about some old problems in new ways.

Montello outlined the topic of the meeting. He first described scale as being concerned both with space and time. He listed four aspects or meanings of scale: (a) cartographic scale -- the ratio of map size to earth size, (b) analysis scale -- the size of the unit of analysis at which a researcher chooses to work, (c) phenomenon scale -- the size at which structures and processes occur, and (d) concepts like detail, granularity, resolution, and generalization, which are partialing overlapping issues that have important though imperfect relationships to the other meanings of scale. Montello then described cognition as being about "knowing": the acquisition, storage, manipulation, and use of knowledge about the world (including oneself). This involved such topics as perception, thinking, memory, imagery, language, learning, concepts and categories, attention, reasoning and problem-solving. Cognition has a reciprocal relationship to behavior -- cognition influences behavior, behavior affects cognition. Alternatively, some would prefer to say that cognition is behavior, and behavior is part of cognition. Finally, geographic information was described as concerning information about the earth's surface, and spatial and nonspatial properties of events and objects found there. Researchers in the geographic information community are especially focused on digital electronic information, such as found in geographic information systems (GIS). Montello expressed the belief that geographers and cartographers had traditionally been interested in phenomena at certain scales, such as cities or continents, and not other scales; participants at this meeting were not bound to restrict themselves in this fashion.

Montello then discussed three representative issues for the meeting. First, he presented his own taxonomy of cognitive spatial scale classes, updated from his paper in the Proceedings of the 1993 Conference on Spatial Information Theory on Elba Island. The taxonomy was based on previous ideas by a variety of researchers on the existence of such scale classes. The various classes refer to real or objective sizes of spaces, though they are determined by the human perceptual/motor implications of spaces of different sizes. These five classes include: (a) "minuscule" -- too small to apprehend without technological aid, (b) "figural" -- large enough to apprehend without technological aid but smaller than the body, and including "pictorial" flat space and "object" 3-D space, (c) "vista" -- significantly larger than the body but visually perceptible from a single vantage point, (d) "environmental" -- larger than the body and otherwise obscured so that considerable body locomotion is required for their apprehension, and (e) "gigantic" -- too large to apprehend without technological aid. These classes are meant as a heuristic device. Montello stressed the need for research on their existence and utility, the possibility that some other classification was better, and the importance of considering the possible implications of such a classification.

Montello's second issue related to the communication of scale and scale changes, particularly through depictions and descriptions on maps and other displays. He cited research on the difficulty even some experts have with the accurate interpretation of the size of landform features from topographic contour maps. Confusion about localization is often related to poor scale translations from a map to the world. Other research considers the difficulties children have in interpreting scale translations form maps.

Montello's third issue concerned questions about cognition and scale in spatial analysis. Is there any research that bears on this issue? It is important to recognize that some processes in the world operate at certain scales and not others. How does the researcher decide on the appropriate scale of analysis? How can the scale of a phenomenon be effectively communicated? What are the implications of this fact for spatial and geographic concepts?

Stan Openshaw
"Optimizing Scale"

Openshaw is interested in spatial data analysis, particularly scale. In this context scale has always been viewed as a problem. He feels the problem is really an opportunity to develop new ways and new approaches to doing spatial analysis. His interest in scale started with the MAUP (modifiable areal unit problem). The problem is that you are actually designing the study by selecting objects. The precise results you obtain depend upon the zones that you use. An example in Leeds is the 2,315 census numeration districts. Typically these aggregate into 63 census areas called wards. People then draw Technicolor maps of these. The problem is that the results you get depend upon the choice of these 63 wards. If you alter the aggregation, you will get different results with the same data. If you can compare two maps with the same data at a different resolution looking at the same variable, you will get a completely different result. Census numeration districts were designed informally for gathering data. If we reaggregate the data into 63 zones, each zone now has the same number of economically active people in it. Now you get a different picture with the same data removing the effect of the varying sizes of the census walls. If we compare this with the previous ward-based map, suddenly new employment black spots appear. Suppose you wanted to prove at a very high probability level that unemployment is correlated with proportion of ethnic minorities. By fiddling with the zones you can get a perfect fit with unemployment r=0.999999, or the converse -0.999999. It is true that you can almost get any result you want with almost any data, but the zones are so extreme that no one could believe them as possibly being useful. This is not to suggest that there isn't an objective reality to be observed, it is to say that ignoring the problem of scale can do great damage. You are no longer sure whether you are a victim to MAUP, or whether what you have found is invariant to it. It is a major source of uncontrolled noise and structure, but on the positive side, it is also a source of analytical power, if we ever become clever enough to tap into it. If we can change what we see in a controlled manner then we may have a new tool.

Zone design is very important in GIS, but we have very few tools for engineering those zones. It is a hard problem because scale is linked to aggregation. It is also difficult because there is very little theory to guide the process. At present we handle scale badly. Most people pretend it is not an issue. The few studies that do exist only use one aggregation to each scale, which is clearly deficient. Even fewer studies of aggregation effects assume that scale is known in advance. In all cases, scale is not really under control. The real problem is that scale and aggregation are inseparably interlinked. The other problem is that spatial patterns are scale sensitive. Therefore we need to know at what scale which patterns are expected to appear. We often don't note this, as we might in an exploratory context.

Scale needs to be explicitly controlled rather than just assumed by the use of certain data. In this context, what scale do we use? Scale can be equated to the number of zones. It is also vaguely related to their size and also to map generalization. For aggregation, you could argue it is the choice of a particular classification of zones to match the scale that is required. If we are vague about scale, then we can be vague about aggregation. If you want to aggregate to N zones, then there are N-1 scales to consider. For each scale, there is also a very large number, especially if N is large, of alternative aggregations. In spatial modeling, most methods assume the scale at which patterns and relationships exist, and assume that the patterns are robust and that scale is not important. There is no way of knowing this in advance. There are very few spatial analysis tools that are multi-scaled or multi-aggregational. Openshaw's "geographical analysis machine" is one of the few.

The point to emphasize is that it is important to think about how you design the zones, and to manage the scale and aggregation components directly. To do this, you need some zone design technology. This is a constrained optimization problem. You need to optimize to try and get the result you want, but you need constraints to insure the results are sensible. The aggregation component in zone design was solved a long time ago by the Automatic Zone Procedure in 1976. The GIS revolution has reemphasized the whole problem. It has been renamed the Zone Design Problem (ZDES). ZDES optimizes any function f(Z), where Z is a zoning system for a given scale. It will produce aggregations of N zones into M bigger zones, such that the zones are topologically connected and are approximately optimized to the function. The key point is the choice of f(Z). This obviously reflects what you want to do. You can pick different functions; you may wish to minimize aggregate travel costs in location analysis, for instance. These problems can then be recast in a zone design context.

What about the choice of M, the number of regions? The problem is that you have to assume it. The solution is to try and build a ZDES algorithm that has both scale and aggregation effects built into it. The problem with that is if you are trying to reengineer your zones, i.e. M varies, it becomes an impossible problem to solve. There is no obvious way of simultaneously optimizing the function of the zoning system and M. What happens if you have the wrong value of M? What are the effects of varying it? The answer is simple. Instead of trying to optimize an f(Z), you want to optimize f(Z) and M. You solve f(Z) for a single M. Say M=2, what is the optimal zoning system? Repeat for M=3, etc. Twenty years ago this would have been impossible, but today these kinds of routines can be run in a few days on a work station. The hardware is now fast enough to allow you to solve lots of design problems.

Then the question is what do you do with all the output? You could have 2,315 maps to stare at. Comparisons by eye become very difficult. On the other hand why not simply animate the scale effects? This will help you zoom through you 2,315 maps. Scale effects now appear as a sequence of optimum aggregations for each scale. One solution is to use MPEG movies. However, that is really complex. A better solution is to use Java. Map animation and scale effects might be one way of dealing with scale. This leads to some sort of multi-scale spatial analysis. Map animation may reveal the secrets of the scale effects. The conjecture is that some function will yield really boring scale patterns that show no real changes because they are stable over multiple scales. Others will show patterns that come and go at different scales. Maybe pattern and scale are intermittent effects. You can also imagine other things like emergence and self-organization behavior.

You might map health data for Northern England, looking for long-term illness. The question is are there any patterns or clusters? If you take all this from the ZDES approach, you search for areas with extreme values. We are trying to engineer zone systems that will maximize this zone function for each scale. By sliding up and down the scale, you are trying to get some feel for what is going on, things change before your eyes. This is a mechanism for exciting your imagination, which allows intuitive interpretation. Openshaw feels that you cannot optimize scale without first optimizing aggregation. But you cannot optimize the aggregation unless you know the scale; therefore you have to treat them both together. The animations of scale effects show interactions between the data being aggregated and the function being optimized. This then gives an opportunity for a new approach. Once you start thinking of scale as being continuous rather than discrete, then you can apply the same technology to other areas of GIS like generalization. Maybe animation can be applied to other areas of GIS.

Jean Sholl
"Are There Different Psychological Scale Classes?"

Sholl studies the various components of the mind/brain system that function to control human navigation in natural environments. So she uses the concept of scale to refer to changes in the sizes of physical spaces. Sholl discussed the notion of cognitive scale classes, particularly as they may apply to spaces the size of a room or smaller. In some contexts, smaller spaces (maps, diagrams, tabletops -- no larger than 2' x 2') may be processed differently than larger spaces (rooms or environments, perhaps at least 10' x 12'). Some processing is scale-invariant. When spaces of either size are viewed and then learned from a single static viewpoint, orientation-specific representations are formed. This is supported by the finding that subjects indicate directions to targets within a configuration faster and more accurately when they are asked to imagine themselves facing in the same orientation from which they learned the space. When they have to answer questions about target directions from an imagined perspective that is different than the one from which they learned the configuration, their answers are slower and/or less accurate. That is called an "alignment effect"; it has been demonstrated with maps and diagrams many times, and it appears to be true of room spaces when viewed in this way. Both configurations of objects and paths laid out on the floor have been tested. Alignment effects suggest orientation-specific coding of place in memory. Perhaps after multiple viewpoints are learned, an orientation-invariant representation can be coded.

But some processing seems to be scale-dependent if there is movement with respect to the test space, specifically if the subject traverses the test space between learning and testing. Given this movement, people do not show alignment effects, or they are weaker, when the space is at least 10' x 12' in size. This suggests the formation of an orientation-free representation of the space. Smaller spaces still show alignment effects. These results depend in part on subject sex. In general, the difference has something to do with the action of the "self-to-object updating" that occurs when people locomote through environmental spaces. Exactly how this updating influences coding in memory is a question for further research. But in some way, movement in larger spaces engages a cognitive navigational system.

Mike Goodchild
"Scale, Resolution, Process"

Goodchild discussed themes of scale in geographic information and environmental process. He first considered the Alexandria Digital Library (ADL), a project ongoing at UCSB. This is a project to put the content and services of the Map and Imagery Library on the Web. It is one of six digital library projects that have been funded over the last four years by NSF and NASA. There are currently almost 1 million "geographic information bearing objects" (GIBOs) in this system, in the form of maps, images, remote sensing images, reference reports, and photographs. The objects are catalogued in various ways. The cataloguing mechanism that Alexandria stresses is also capable of referencing and retrieving information which is referenced by geographic location, but which is not necessarily a GIBO. For example, a guidebook of Paris has a well defined footprint on the Earth's surface, is findable by the same mechanism used for maps and images of Paris. Geographically-referenced information objects is a broader class than is GIBOs. The typical user of a map library asks as the primary query: "What have you got that deals with there?" Location is the primary key. That defines Alexandria and is what they are calling a "geolibrary". Secondary keys, things one asks to narrow the search, include theme -- soils, date, etc.

An important query key is level of detail. A query about Santa Barbara County could return a map of the entire Earth which includes Santa Barbara County, a map of the US, a map of California, a map of part of Santa Barbara county, all the way down to a map of someone's backyard. One has to define the key of level of detail. In the traditional map library, that function is often performed by a human expert. It can be argued that the role of human expertise in a map library is much larger than the role of human expertise in a normal library. It requires a great deal of interaction between user and the librarian to make a map library work. The cataloging problem in a map library is much more difficult than it is for conventional books. There isn't a finite discrete catalog for geographic location.

Suppose a child of 10 wants a map of his/her neighborhood. The question is what kind of mechanisms can be set up to allow that child to specify the requisite levels of information. Within Alexandria and the domain of geographic information, there are ways of specifying levels of geographic detail. These are represented for example by the Federal Geographic Data Committee's Content Standard for geospatial meta-data. Maps traditionally have used the representative fraction (RF) as the method of specifying the level of detail, the ratio of distance on the map to distance on the ground. It is well defined for paper GIBOs such as a road map. But is the RF understandable to a child of 10?

What happens to the RF when you move into the digital world? Herein lies a large number of problems. The notion of RF is somewhat unsatisfactory because it is impossible to produce a paper GIBO on which the RF is constant everywhere. A famous example is the airbrushed image of Earth produced by Van Sant at a 4 km resolution. Early editions had on the bottom: scale 1 inch = 720 miles. On later editions it had a note underneath it, saying "on the equator". In the digital world, the RF is undefined, because there is no single external representation but a digital database. However, the RF is still the dominant method of specifying local detail for digital GIBOs. That has been maintained through the preservation of the legacy, in a series of conventions. Unfortunately, as time goes on, these conventions have gotten more and more complex. These have made the whole system inaccessible to the child of 10.

On a 1:24,000 topographic map, the level of detail is defined by the RF. Level of detail is a surrogate for positional accuracy. The national Map Accuracy Standards connect the two. They say at a given scale, a map has positional accuracy of say 1/40 of an inch, which translates into 12 meters on a 1:24,000 topographic map. In addition, the representative fraction stands as a surrogate for spatial resolution, there is a vague relationship between 12 meters and the kinds of objects that you can display at 1:24,000. The spatial extent of a 1:24,000 quad is about 15 km. Goodchild defined a measure "large over small" or LOS. Take the extent and divide by the spatial resolution, it is an order of 10^5. That is a dimensionless number. That is persistent across the various scales of topographic maps. RF on an analog aerial photograph is defined by convention by the lens of the camera, its focal plane. But I can enlarge a photo, changing the RF. This was a way of defining representative fraction that was persistent across enlarging and reducing.

Now to some digital problems. Landsat Thematic Mapper imagery is an example of remote sensing imagery. Here the positional accuracy of a typical image is often quoted as 3 pixels. That reflects the ability to recognize an object in a scene, and also to recognize on the ground. Spatial resolution is the pixel size, which is 30 meters for Thematic Mapper. The RF by convention is not defined. But we can take its spatial resolution and compare it to the scale of a topographic map where we would get that resolution, and then make an inference. One could reasonably say that 30 meters corresponded to a mapping scale of 1:60,000 by convention. The extent of a thematic mapper scene is about 100 km. LOS is on the order of 10^5. The digital orthophoto quad is a new kind of product coming from USGS. It consists of an aerial photograph in digital form that has never been on paper. There has never been a way of defining RF on this. It has pixels that are 1 meter, the spatial resolution is 1 meter. The USGS defines its representative fraction as 1:12,000. The convention that establishes that is that the positional accuracy is 6 meters, which is what the National Map Accuracy Standard say should be the positional accuracy for 1:12,000 RF. There is a lot of complexity to the conventions, they are becoming more and more complex, because representative fraction is a legacy of the paper era. The LOS is a dimensionless number remarkably persistent at about 10^3. An interesting question is whether there is something about a persistence of large over small in terms of our ability to handle information.

The RF is not going to be able to handle communicating scale in the digital world. If you look at the way Microsoft has structured its Encarta Atlas, there is never a projection. The Earth is always seen orthographically as it appears from space. Nowhere in Encarta is there a scale, an RF. Instead, Encarta uses the metaphor of the height of the eye above the Earth's surface. If you want more detail, Encarta invites you to slide the eye down a scale in order to bring it closer to Earth. This is of course robust against digital versus analog. One problem with it is that there are no familiar landmarks on this sliding scale. How does the child of 10 know he/she is 500 km above the Earth's surface? The solution is to establish landmarks at that scale, landmarks in terms of spatial resolution. For instance,
10 meters might be the resolution at which one can see the houses.

Goodchild then turned to an interesting discussion of processes which affect scale. Is it possible to develop a theory of general principals about scale and physical processes? He defined resolution as the minimum distance over which change is recorded, or change is represented, or change is visible, or change is detectable. This is a useful way of thinking about resolution because it connects change in some variable to distance on the Earth's surface. A gradient connects the two. If one says there is a class of processes that increase relative gradient, then those are necessarily processes which require a higher resolution in the output than in the input. The input at a point, for example, is temperature. The output is some response variable. If that process is non-linear, then spatial gradients in the input become steeper than in the output, and therefore require a higher resolution. This is true even though the process is aspatial -- the output at a point is related only to the input at a point. This is heading for a class of processes which affect spatial resolution by changing the resolution between the input and output. These are processes that increase relative gradient, that require a higher resolution in the output. By the converse, if processes decrease relative gradient, they can have lower resolution in the output.

A second class are processes that in some way integrate or average, or aggregate spatially. The response variable G at some point S is an integration over space of the input variable of some other point multiplied by a weight. These are convolution, averaging, or smoothing functions. A typical example is resource use. The success of an individual organism can be represented as an integration over its resource base or territory. In that sense, the response variable has a coarser spatial resolution than the input variable.

The third class of processes has to do with the actions of discrete entities, or discrete organisms. For example, imagine an organism whose behavior is to locate at a position of maximum resources, a new shopping center or a scavenging organism. The result of this process is to convert a smooth, or even a uniform resource base, into a non-uniform response. In some places there are organisms, and in other places there are not.

There are also classes of processes which require direct interaction between individual organisms. Processes of competition for space, where there is a tendency for organisms to maximize the inter-organism distance, or clustering processes which bring them together. All of these are examples of a uniform resource base which produces a non-uniform response. A coarse input producing a high resolution output. With many of these we probably need to introduce an element of randomness if the resource base is actually uniform, in order to produce a non-uniform response. Many of these are chaotic processes.

In all of this, Goodchild is trying to classify processes in terms of what they do to scale or resolution. The practical implication is that this is a way in which we can anticipate what is needed in a GIS, for example when the input has a certain representation, a certain scale. We are trying to predict the necessary resolution of the output. In most cases, what we do in practice with GIS is to assume that the input resolution determines the output resolution. We map from one to the other. In most of these cases, that isn't reasonable, as the process actually effects the resolution.

Christian Freksa
"Scale and Detail: A Representation-Theoretic Perspective"

Freksa focused on issues related to scale and representation, whether internal or external. He described scale as being an issue in different "worlds": the 'real' world, the 'model' world, and the relation between the two. The term "scale" is used differently in these three worlds. In the real world, scale refers to object or space size; we could say "large space" instead of "large-scale space". In abstract model worlds, we speak of the decimal scale, logarithmic scale, etc. When we relate the real and model worlds, we are talking about a transformation or mapping between these two worlds. For example, the concept of map scale implies that larger scale means a larger model world for the same size real world.

Palmer's Representation Theory identifies five components of any representation system (Figure A): the represented world (W1), the representing world (W2), the aspects of the represented world that are being modeled (R1), the aspects of the representing world that are doing the modeling (R2), and the correspondences between the two domains (C). This mapping is not trivial, in general. We usually do this to solve certain tasks.

For example, we may want to use a road map to determine a route which gets us to some destination as quickly as possible. Given only a road map, you have represented locations and their interconnections. You will make all sorts of inferences just from this spatial layout, but the layout itself is not what you are interested in. Time is usually not explicitly represented. But it can be derived from at least three types of knowledge. These include world knowledge about roads and traveling speeds; more general physics knowledge about relations between distance, speed, duration, starting and arrival times; and knowledge about geometry and map symbols, transformation of map scale, and relations between orientation and distance. Scale applies to all three types of knowledge, real world knowledge, model world knowledge, and their correspondence. Knowledge about the real world is very debatable. For example, we might have specific knowledge about traveling, about the time and the roads. Travel sped is high when roads are straight, and so on. This is the type of knowledge that requires experience about traveling. The more abstract physics knowledge, the model world, might be knowing that the arrival time is early when the departure time is early, and so on. One may have more sophisticated knowledge, such as that travel time is proportional to distance divided by average travel speed. We my have geometric knowledge, for instance, that the distance is shorter when the direction is fairly straight or the road is not curvy. It may be very difficult to apply geometric knowledge that we can deal very well when we are working with triangles to the real world situation. This may lead to debates between driver and the copilot!

When you look at the correspondence knowledge between the map and the real world, you may have some basic assumptions. For example, that there is a freeway in the real world when there is a freeway symbol on the map. We may assume that a sign for information applies everywhere on the map. We have some knowledge about the misbehavior of this correspondence, for example that small items can disappear. Not many map users are aware that large items can become rather small, while small items in the same region can stay large. An example might be roads in the mountains and in the valley. You may have a very long winding road in the mountains, which appears rather short when generalized at a different scale, while the valley road may not change much when we change scale. From that we may learn that distances in the map only provide a lower limit on distance in the world. The distance can be very much larger.

The problem of abstraction and scaling can exist on very different levels. The most commonly discussed level would be quantitative scaling, where certain features get shown and others disappear. When we think in terms of qualitative classes, we may get some modified number of relevant categories. This is closely related to the quantitative, but is still an important abstraction for certain tasks which you may want to answer in terms of categories. Conceptual scaling occurs when you have to decide which conceptual dimensions you want to represent in the map. Since our concepts usually are not orthogonal to one another, if we drop some dimensions, we can still use the representation to infer indirectly other concepts. There are no strict rules, but like in the travel example there are some heuristics about which decision to take that we can use.

Freksa then discussed the semantics of qualitative scale, which he equated with linguistic scale. We may have linguistic labels like 'very small', 'small', 'medium', 'large', and 'very large'. This is sort of a natural order for these labels, so they form some sort of a scale. There are two views about what such labels may mean. One view is presented by fuzzy set theory, which gives an explanation under a system of absolute size indication. A fuzzy set would indicate the membership of an object of a given size in the fuzzy set of, say, small objects for this world. For example, objects of this size would be small to a degree of 0.8. Each individual label would have its own interpretation. This leads to the problem that the meaning of these labels is only valid in a very specific context which must be specified (Figure B). For example the size of people, etc. It doesn't make much sense to compare a large person to a small dog, or something like that.

On the other hand, if we think about these labels without saying to what they refer, they hold a certain meaning for us at the conceptual level. The great thing about natural language is that you can use these labels and apply them to very different contexts. So this induces the second view that we will take, that we have relative values. We would all agree that if I call something "very small" and a moment later something else "small", then probably the one that is very small is smaller than the one called small, and so on (Figure C). So fuzziness on the level of these linguistic labels is not such a big issue. So independent of any scale, we probably could order these labels, and could order these objects here, without knowing how big they are in the real world. If a child is asked to make a correspondence, and is given these labels, one would be called very small, one would be called small, and so on. Here we have a structure. This structure exists completely independently of the specific application. So this is a structure in our model world, W2, to be mapped onto structure in W1. We can map this as a whole structure rather than as individuals. We may get an disorderly thing if we look at objects individually.

Here I want to suggest that we can match, but in describing objects or judgments. When we do not know enough to give numerical values, for example, but have enough knowledge to give some qualitative judgments, we must make sure that we do not overinterpret. In this case, for example, our knowledge is lacking with respect to specific size, so all you can do here is make a qualitative description. By making these comparisons and matching these structures, you can actually get a coherent description, which we would not get when we try to interpret a very precise semantic for which we do not have sufficient information.

Tim McNamara
"Spatial Representation and Scale"

McNamara began by defining "spatial representation" as: How people mentally represent spatial information, particularly locations of objects. His major theme was the question of whether there is evidence that different kinds of spatial representations are used at different scales, interpreted as size. His talk was structured around two principles of spatial representation and processing supported by his research (along with his collaborators) and that of others. The first is that locations of objects in the surrounding environment are represented in memory in "orientation-dependent" reference systems. The second principle is "scale invariance": At least at the different scales that have been looked at systematically, we always find evidence of orientation-dependent coding of location. With objects, maps, room-size spaces, and pretty large complex paths like field size, we see that location is mentally represented in an orientation-dependent manner, at least in part.

McNamara pointed out that location is inherently relative. It has to be defined with respect to something, and the something is a spatial reference system. In psychology, lots of different kind of spatial reference systems have been proposed. There have been distinctions between intrinsic reference systems and deictic, object and scene-centered vs. viewer centered, absolute versus relative. This last term is an ambiguity. In psychology, relative is used to mean relative to the observer, not relative to objects in space -- egocentric vs. allocentric. Several of these terms can be grouped as examples of orientation-independent systems: intrinsic, object/scene-centered, absolute, and allocentric. Location is represented independently of the orientation of the observer. Other terms can be grouped as examples of orientation-dependent systems: deictic, viewer-centered, relative, and egocentric. Location is represented in terms of the observer's location or orientation in space at the time in which it is learned.

How do we tell orientation-independent and orientation-dependent systems of reference apart? The way that everyone in the field has done it has to do with the relative accessibility of views. We give people an experience with a space or an object, and then put them in a situation where they have to make some kind of spatial judgment. The question is: Are spatial judgments easier (faster, more accurate) from familiar views than from unfamiliar views? If they are, that provides evidence that spatial structure is represented in an orientation-dependent manner. On the other hand, if familiar views and unfamiliar views can be imagined, retrieved, and processed equally easily, then that constitutes evidence that spatial structure is represented in an orientation-independent manner. McNamara then presented data from research in his lab based on that distinction.

As an example, he showed the stimulus pattern in Figure D. It is a 4-point path first introduced into the literature by Levine. Workshop participants were asked to memorize it. Then they were asked to answer questions such as: "Imagine you are standing at 1 facing 2, and point to 3" or "Imagine that you are at 3 facing 4, and point to 1". The first judgment is a lot easier than the second, because your imagined heading in the first judgment was "aligned" with the perspective of the scene that you got when you experienced it. The second imagined heading (at 3 facing 4) is "misaligned" with the orientation of the figure when experienced.

McNamara is not claiming (nor is anyone else) that people can't use orientation-independent coordinate systems like latitude and longitude, state plane, or UTM. People, especially experts, can obviously use those orientation-independent frames of reference. The point is that when people learn where objects are in their environment, or when they first learn a spatial structure of some kind, that spatial structure is mentally represented in an orientation-dependent manner, at least initially. What happens with expertise is an open question. What is an expert? It could be someone that is expert in a space, with a space, or with some kind of spatial structure. Do they form in memory orientation-independent, 3D or 4D, dynamic representations? Or is it the case that what an expert has is just a whole bunch of orientation-dependent views? If you get enough views of a space, you are going to be able to access all of those views roughly equally well, and your behavior is going to appear to be orientation-independent.

What difference does it make and who cares? It is a fundamental issue in spatial memory -- how things get represented in memory. But it also matters behaviorally in many ways. One example concerns ways that people get lost. One way follows from how spatial information is represented in an orientation-dependent manner. Many times, people get lost because they don't recognize the appearance of the trail looking in the other direction. The 'look-back' strategy, in which you periodically turn around and look back at the view in the opposite direction, is so effective for this reason.

McNamara then described research findings on object recognition by Edelman, by Rock, by Tarr, and their colleagues. This is fundamental to robotics and computer vision. How do we recognize familiar and unfamiliar objects from various perspectives? There has been a lot of work done on this problem, and the near total consensus is that the spatial structure of objects, that is the location of features and parts, are represented in orientation-dependent frames of reference. Evidence indicates that multiple views of a single object produce multiple orientation-dependent representations in memory. People look at unfamiliar and artificial objects from one or more points-of-view. When errors in recognition are plotted as a function of angular rotation from one of the training views, you see that errors generally go up as a function of angular distance from that perspective. This indicates that there is some cost associated with recognizing an object from an unfamiliar novel view.

It seems that room-size and larger spaces are represented in an orientation-dependent manner too. McNamara described some of his research with his students that support this idea. For instance, in one study, people walked into a room where there was a collection of seven objects on the floor, and their job was to learn where the objects were. They got two views of the configuration (Figure E). Subjects would stand at what is called 0 degrees and study the collection of objects for 30 seconds. Then they were blindfolded, and asked to point to and name all of the objects. When they could do that twice correctly, they were then escorted blindfolded to the 90 degrees perspective and asked to do the whole thing over again. After they have learned the configuration from two perspectives, subjects are taken into a different room and are asked to make judgments of relative direction. Subjects are given problems such as "Imagine you are at the book facing the wood -- point to the clock". Pointing accuracy and latency are recorded as a function of the imagined point-of-view. People were much more accurate pointing to objects when the imagined heading was one they had experienced, that is, 0 or 90 degrees. Novel headings such as 45 degrees were more difficult than the familiar headings (Figure E). This is evidence of orientation-dependent coding of location. In particular it looks like what people are representing are just two independent views, the 0 degree view and the 90-degree view.

McNamara described other studies he and his students have done that support the privileged status of familiar views, but qualify it by showing that the walls of the testing room provide a reference frame for spatial memory. Configurations learned from viewing perspectives that are not parallel or orthogonal to the rectilinear room are hardly even stored in memory. In a cylindrical room, people could learn the configuration from any view they saw first, but they showed little evidence of storing any of the other views to which they were subsequently exposed. Transformations of the configuration to perspectives differing by 180 degrees appeared to be a bit easier than other transformations.

Many other people have shown similar results. A critical question concerns what role locomotion plays. Almost nothing is known about whether movement at the time a space is learned facilitates or inhibits the construction in memory of an orientation-independent representation. Another big research question concerns what happens with environmental and geographic spaces.

III. Breakout Sessions

Breakout sessions were small-group discussions of specific topics, listed below by arbitrary group number. Topics came from the initial ideas of the organizers and ideas provided by participants during the meeting. Each group had 4-9 members with one or more graduate students attending as raporteurs and participants. In many ways, the Breakout sessions were the heart of the meeting. The most detailed and in-depth discussions took place there, and most of the research questions were probably generated as a result of these discussions. The summaries that follow are based on transcriptions from the tape recorded Breakout sessions, and recordings and notes from the summary reports given in plenary sessions after the Breakout sessions (including ensuing comments and discussion). It is clear that ideas generated earlier in the meeting were redundantly discussed later in the meeting. Some of the redundancies are removed from later summaries, others will be apparent when reading them.

We do not identify the specific members of each Breakout group in this report, nor do we attribute specific ideas to specific participants. In many cases, it is impossible to definitely attribute statements made to a specific person. But perhaps more importantly, many of the ideas contained in this report emerged from the synergistic interaction of two or more participants and are not appropriately attributed to the single individual who happened to vocalize them.

Breakout Session #1, Group 1
Cognitive Scale Classes

This group discussed the notion of discrete cognitive scale classes, such as those presented by Montello in his Plenary Paper. The group strongly endorsed the view that behavioral functionality, what you do or can do in spaces of different sizes, or activity, which perceptual or motor systems operate in spaces of different sizes, are the appropriate bases for any valid classification. Perceptual activities include touching, hearing, looking, and so on. Motor activities include grasping, crawling, walking, driving, and so on. Scale is a concept of relative magnitude, and looked at in these ways, spaces is scaled relative to the human body -- humans are the measure of space. The distinction between spaces you can sense from a single viewpoint vs. those you cannot was seen to have particularly fundamental consequences for the form of internal representations.

Several alternative bases or systems for constructing scale classes were discussed. Space becomes flattened and less multi-modal as you go further away from a person. Another participant mentioned near-action space, far-action space, and background space. Scale was said to be important in representing figure-ground relationships; what is the figure and what is the ground varies with scale. In local space, there are perceptual figure-ground distinctions; in distant space, the figure-ground distinctions are entirely cognitive. A case was made that people update their location relative to surrounding space, such as a room, but not to smaller space, such as a map. Some evidence by Rieser and by Simons shows that people can update within a small diagram or map space if they are instructed to, but it is not natural or automatic. In a sense, small things are objectified. This suggests a pervasive distinction between things outside of us and things into which we enter or move about. The reference system used to encode space was considered to provide a possible basis for scale classes. Body-centered, view-centered, object-centered, or other external frames are examples discussed.

There was fairly strong consensus that some type of cognitive scale distinctions made conceptual, functional, or intuitive sense. However, a couple people in the group made strong arguments that there really is very little empirical evidence for such distinctions, or for the importance or utility of trying to make such distinctions. One of the most discussed examples of possible evidence is the notion that smaller spaces (such as maps) are learned and stored in memory in an "orientation-fixed" or "dependent" manner, while larger spaces (such as a city) are stored in an "orientation-free" manner. In the orientation-fixed case, judgments such as indicating directions between points in the space would be fastest and most accurate when made from the orientation in which the space was learned (north at the top of a map, for instance). In the orientation-free case, judgments would be equally fast and accurate in whatever orientation was asked. Orientation-free representations would support flexible use of spatial information, though at a cost. In fact, most of the major researchers on this issue were present at this meeting. The existence of orientation-free spatial representations has proven very difficult to replicate. Some participants made the case that judgments would always reflect some preferential orientation or reference frame, whether map alignment, room shape, or dominant street pattern. Familiar views of a space are easier to retrieve than unfamiliar views, no matter the scale of the space. People can generate alternate perspectives or views on a space, it is just more difficult. A distinction between orientation in long-term memory vs. working memory was considered to play a role. The need for more research on even larger spaces was also discussed.

Other possible evidence for scale classes, or reasons why it might be valid, were discussed. Even the strongest skeptics of orientation-free memory agreed that there might be other phenomena that could support the distinction. The issue of motivation was discussed. Many experiments are not very engaging and might produce different data than would result if people were very motivated to try and learn spatial information. Individuals were thought to differ greatly with respect to their natural interest in such activities. The possibility was raised that people refer to location differently depending on scale. An example is a "bird's-eye" perspective vs. a "tour" perspective, investigated by Linde and Labov, and by Tversky and Taylor. Another possibility is that objects in certain scales of space can move. Mountains don't (apparently) move but things in tabletop space do. Also discussed was the fact that spatial relations in environmental spaces are learned much more effectively and efficiently from a map than from direct experience locomoting about the environment. Perhaps scale classes reflect cognitive limitations in our ability to integrate information over long periods of time and over large spaces. One participant suggested that scale classes emerge out of a fusion of our sensory systems, our cognitive systems, and the nature of our world.

An interesting discussion took place about hierarchies in spatial representations. Spaces at different scales might define different levels of a hierarchy in the mind and/or in the world. An example might be traveling from Santa Barbara to San Francisco. There would be a variety of spaces and scales, such as room space, hotel space, local space, freeway space, and back to local space. The different levels might have the same ontology (types of objects and operations therein) or different ontologies. In the former case, it would essentially be a question of resolution or granularity only. The scales would coexist. They would have a nested organization relevant to the particular task being performed, such as planning a route. At different stages of the trip, a person would be orientated to different scales, different resolutions. Such a hierarchy would nonetheless support the notion of scale classes. This led to a discussion of the role of task in defining scales. Task and scale covary, and researchers should try to pull them apart when they study scale.

Breakout Session #1, Group 2
Communicating and Representing Scale and Scale Changes

This group focused on ways to communicate scale and changes in scale, primarily through cartographic depiction. This is external representation. Some discussion of the internal representation of scale in data models also occurred.

The group discussed various tasks using geographic information, including navigation, reference tasks, and analytical tasks. In navigation tasks, such as vehicle or personal navigation, representations of scale could be verbal, audio, haptic, visual, or any combination of these. An audio scale bar, for instance, might work by pinging at a certain frequency depending on how far along or away you were. Differences between vision and touch were discussed, such as the fact that touch limits your scale flexibility much more than vision does. Haptic representation of scale could include resistance on a track ball that would vary according to the scale. The group couldn't decide on a good way of equating how much distance was equivalent to how much resistance. The contrast between relative and absolute scale kept coming up. How much detail do you need in a verbal description as opposed to a haptic representation for navigational purposes? Do you need information just at decision points? When giving directions to some place, it may be important to give information in a context ("the gate after the bridge"). The level of detail relates to the relevance of the detail. Other kinds of clipping of detail occur because of social relevance or political correctness.

Different classes of users were contrasted, such as a 10-year old child and an expert user. Children certainly have problems with scale comprehension. Elementary cartography offers three ways of representing scale, a verbal representation such as "one inch equals one mile", a numerical representation such as 1:63,360, and a graphical scale bar. The view was expressed that scale change should be somehow shown graphically rather than verbally. The expectations or motivations of the user were thought to be important. What do children need to do a third-grade report? Would they need to know something about the forest, or the trees in the forest, or the owl that lives in the trees in the forest? Over time you would build up expectations about the types of things you would expect to see, in terms of resolution and scale. This suggests an issue of multiple entry points based on the sophistication of the user.

Analytical tasks involve finding out about the world. This is about finding patterns, epidemic patterns or patterns of erosion or whatever. Here the task involves identification, detection, interpretation, and hypothesis formulation. It is quite reasonable to expect that that hypothesis formulation will depend on the scale of the data that is available. It will also depend on the type of process and the type of question.

Standard data models, such as vector or raster, have geometries that may vary across the map but are agreed upon. Our ability to represent things with GIS is quite constrained. Changing scale in a vector representation requires changing form. This is a step function. One participant made a strong case that changing scale in a vector world does not require a change in form. You can do continuous scale changes with vectors if you apply an algorithm that does a continuous scale change on the vector space, in which case step functions will not happen. What you will find is that features will coalesce and disappear. In other words, you can treat the vector as a raster image. Other group members disagreed that scale changes in a vector representation can occur continuously.

One can see that step function in the 'Powers of Ten' video (shown at the meeting). Things appear and then change, then reappear and then change. That involved a raster image on which you can infinitely zoom in and out, you either see the pixels or you don't. Scale operates differently in a vector display, as when symbol sizes are exaggerated out of scale in order to make them visible. Think of a map as a vector image made up of symbols and scaled features like roads. As you change the scale, the exaggerated road is suddenly going to fill the whole screen, so you need a step to change the symbol size. For example, as scale changes a motorway goes from 3 lanes to 1 lane to a single line. The entity view of geographic information is that space is a container. It has objects in the container, points and lines and polygons. If you want to change the size of these things, you have to change the form of the points and lines and polygons. The depiction of features is thus a step function, whereas with a raster image, you can zoom in and out indefinitely.

In a virtual world, the representations of things are much richer. There are other indicators of scale that are available in the virtual world. Pauch's system was discussed (described in Session 2, Group 3 on Scale in Virtual Worlds). One way to communicate scale is the size-distance relationships among objects. Another is speed, how fast you appear to move through the space. The speed may be fixed or variable. This richness of implicit indicators of scale is dictated in part by the form of the representation. In cyber-reality, you have a medium not a representation. And changing scale there can be continuous. This continuity of changing scale, this seamless change, is the ideal.

The group then considered measurement. As we go from very small units to very large units, as you reduce the resolution, a measurement tends to go out the window. The length of a river will increase as you increase the resolution, at some rate. At a certain point it will change dramatically - you will resolve the oxbows and the meanders. All of a sudden that length will increase substantially, so the rate of change will change. It was thought that physical features tend to change more dramatically and more often than human or cultural features.

Our technology allows us to record things at a regular resolution; pixels are a fixed size. But reality doesn't happen at regular intervals; therefore, we have this discrepancy between the things we wish to represent, and the scale or the resolution at which they are acquired. As you reduce the resolution you go to finer and finer spatial units, or finer and finer time increments. There is a sense that you are going to be able to solve all your problems with a data base of infinite or at least very high resolution. That may or may not be the case. One may have higher resolution and more detail than is needed. In an archeological database, for example, you have information at different temporal scales with different levels of detail (a village and a campfire). If you record data at too fine or too coarse a resolution you could miss these events. In addition, the appropriate scale across the data plane may vary, the resolution of the attributes at the campfire may be very high while the resolution of the village may be lower. The analytical tools that one has may not be available at all scales or levels of detail. At a certain point, you need to modify your analytical tools by aggregating data or applying a different model.

Spatial scale is not just about distance. One could go relatively quickly from one end of a U.S. state to the other, but in Scotland one can only go about 30 mph. So in this context, scale is about a type of distance that is relevant to the task, such as travel time. The important thing here is to deal with scale in a way that is relevant to a person's experience of the task at hand. In Europe, generally speaking, you would have a map per a certain area (more or less than one country), and it would be at a set scale. One page will cover so many kilometers. In the U.S., atlases have one page per state and scale varies greatly across map pages. Virginia typically gets as much map space as Alaska.

Some symbolic methods of communicating scale were discussed. A locator inset would be a smaller scale map which would show where the area represented on the larger scale map is located, and also how large it is compared to some other, presumably well known entity. A continuous zoom function in a computer map creates some difficulties in communicating scale. In an old-fashioned map, there may be two fixed scales such that if you click on 1:10,000 or 1:50,000, you get two different things. If you use a continuous zoom bar, it is a different and harder problem. There aren't discrete scale jumps. Zooming can be thought of as shrinking or expanding the environment, or as the user moving though space. For instance, when watching the movie 'Powers of Ten', one can think of it as the world changing scale or the viewer moving up or down. If you are trying to create an effective sense of changing scale, would it be good to illicit the sense of movement through space as opposed to changing the size of the thing represented?

Work on zooming in and out of an abstract space, such as in a digital library, was mentioned as another example of the difficulty of staying oriented to the scale at which you are located in a digital database. The group considered ways in which moving through the Web is or is not like moving through a hierarchy. They also discussed new metaphors for communicating scale in cyberspace. For example, some Web sites that allow zooming have something like a scale bar, which is a line of circles. The line of circles indicates the scale of the view. It might start at regional and go down through city. You could have labels that relate to a specific process that occurs at a certain scale. An example from the domain of weather is "mesocyclone". One could use something whose scale is known to understand something very different, even if inappropriate in a literal sense. You may be looking down from a satellite to earth and see a mess of stuff, and you say, "that looks like a ball of string." You are using the metaphor to give you comprehension. You couldn't discern a ball of string from space, but you use terms from a different scale to give meaning to the thing you are observing. Metaphors promote the mapping of scales.

Technology has opened doors to experiment on scale perception and ask all kinds of questions. We can experiment with scale by considering a wide variety of different scales and perspectives. It raises some intriguing questions as well. What can we do with it? What are its limitations? We can get something that may be very intriguing or busy looking. But on the other hand how much can we really understand from some of these displays? As in other groups, a discussion ensued on the degree to which people will adapt to new perspectives and visualizations, or have trouble understanding them because of evolutionary or experiential constraints. How will the natural scale of our perception/action systems interact with very unusual scale representations?

Breakout Session #1, Group 3
Aggregation and Scale in Spatial Analysis

This group discussed spatial analysis, particularly issues of identifying the appropriate scale of analysis to fit the scale of a phenomenon. Much of the discussion centered around an attempt to identify the cognitive angle on aggregation and scale in spatial analysis. In an important sense, anytime you're talking about how people understand something, such as a spatial analyst trying to understand patterns in data, you are dealing with a cognitive issue. The challenge for anyone addressing this topic is to try and find ways that the theories and methods of cognitive science may be applied.

Multiscale categorization was discussed. An analyst deciding on land cover classes was used as a prototypical problem. A major reason for a cognitive approach would be to automate land cover recognition and classification. Currently this is done by "experts". One problem is trying to combine data layers at different scales, such as 1:10,000 and 1:250,000. Another is combining data from different themes. Finally, land cover classification is not done according to formal rules, and different experts sometimes use different classification systems. Expert systems work is potentially useful here (and being pursued).

Another cognitive angle was the question of how analysts can decide upon the appropriate unit of analysis for a given problem. This led to discussion of ways to visualize alternative unit sizes and shapes, the so-called modifiable areal unit problem (MAUP) well known in spatial analysis. The idea that phenomena can exist at multiple scales simultaneously was appealing to the group, but seen as very difficult for the analyst to determine and to communicate to others. The context of a problem was thought to be important for the recognition of patterns at various scales. The way data are visualized definitely affects how patterns are recognized, and which scales of analysis and scales of the phenomena are identified as appropriate.

Data-driven vs. model-driven data analysis was discussed. Some of the analytic tools that have been devised (by meeting participants and others) were seen as being potentially dangerous insofar as they are typically atheoretical searches for pattern with the aid of high-powered computer algorithms that would frequently capitalize on chance. Here, the distinction between exploratory and confirmatory analysis is critical.

Breakout Session #1, Group 4
Understanding Scale and Scale Changes by Subpopulations

This group began by listing subpopulations or characteristics of people that might be relevant to an understanding of differences among individuals in their understanding of scale and scale changes. These included: (a) age (children, adults, the elderly), (b) sex or gender, (c) visual or other sensory disabilities, (d) physical or motor disabilities, (e) cognitive disabilities, (f) expertise, and (g) cultures and residential environments.

One issue considered was how scale manifests itself upon individuals to constrain or contextualize their behavior. For example, vision provides essential information about spatial layouts at a distance which is not available to the visually impaired. Children are not allowed to travel as far as adults, which constrains their understanding of spatial extent. It was noted that the world of a child is different than that of an adult, in part because they operate in differently scaled spaces. Similarly, women in most societies have constrained activity spaces compared to men. Much has been researched and written on ways that the activity spaces of women might influence their outlook on the scales of politics and community. Another point was made that subpopulation membership influences access to scale or things that represent scale. Making children mobile either through walkers or natural development does change their ability to experience scale. Another developmental difference can be caused by access to maps and the use of maps. There is a fairly consistent finding that girls' range of explorations (home range) is much less than that of boys in virtually all cultures. Differential access to automobiles, airplanes, or mass transit is another important example. These examples relate to notions of social and political scales. Perhaps paradoxically, children may literally play with scale more than adults, as with toys. Some scale violations don't bother them as much.

Another important issue was the question of how scale classes might differ as function of subpopulation characteristics. This has special force with respect to sensory or motor differences, as sensory/motor activities were widely seen at the meeting to be a basis for cognitive scale classes. Also, the functions that different subpopulations can carry out in spaces of different sizes are not identical. For example, tabletop space is the area where we have evolved to deal with graspable objects. The objects are usually stationary and we are acting on those objects. A lot of our cognitive processes are not abstract, they have not evolved in a void. They have evolved to help us work in particular settings. Children have smaller bodies and shorter reaches. The visually impaired probably would not distinguish spaces beyond their reach or locomotion on the basis of visual properties. One participant discussed research on people in wheel chairs. The subjects focused on travel time and effort (such as opening heavy doors) rather than physical distance. Similar arguments could be made for scale understanding by the elderly. The interesting point was made that one could argue that function defines different subpopulations through scale, rather than the common argument at the meeting that function defines scale.

Characteristics of subpopulations have important implications for research methodologies for studying scale. Instead of treating scale classes as objective realities, one might see them as constructions of researchers that may or may not coincide with the constructions of certain subpopulations. Cognitive scale may be a continuum upon which certain methodologies establish non-universal boundaries. In nearly all research, the scale is preset by the researcher, and subjects cannot scale up or down. Most child research reflects an adult way of looking at the child's world. Research such as that by Liben and Downs suggests that children evidence scale confusions about objects on maps, such as saying that a line cannot be a road because it is too narrow for a a car. But children may in fact be able to embrace multiple scales. Other people have used a sandbox task, where they bury a toy in a sandbox and ask the child to find it. Then they give them a scaled map. Very young children did very well on this task. The influence of the task on the research results comes up again here. How well could people demonstrate orientation flexibility if they were analyzing a billiards table rather than performing tasks such as those in the Plenary Papers of Sholl and of McNamara. Similarly, sighted researchers investigate the degree to which blind individuals understand the scale concepts of the sighted, rather than trying to understand scale as the blind person understands it. What scale classes might result from looking at audition rather than vision?

An alternative viewpoint was expressed that most people seem to understand certain scale concepts even if they are constructions -- people are taught to use them. In fact, there is a real world out there with real structure. One has to navigate in an environment that is actually there. Much of this may be a cultural convention or invention. But the modal adult's body and sensory systems are not cultural inventions, and they are responsible for much of the structuring of the built environment. When we structure the space the way we do, we require of people certain things. Efforts such as orientation and mobility training are carried out to try to help people cope with the way the world is structured.

Symbolic representations will always be discontinuous. One has to go through scaling and transformation. Static maps may be of the same size, but they represent different areas. People without sight may have difficulty making this jump, as it appears children do. However, a need for research exploring the degree to which different subpopulations understand scale was noted. Developmental and cross-cultural research should be done to help us examine the validity of assumptions about universality.

Temporal scale was discussed. Children have a sense of time as the flow of events that is somewhat superseded in adults by clock time. Different activity spaces and space-time budgets differentially influence the understanding of temporal scales. Some nonobvious implications of subpopulations were discussed. For example, teenagers may sit in their room interacting over the Internet with very large-scale space, an unusual experience for some adults. This would affect the teenager's sense of scale and community.

Breakout Session #2, Group 1
Spatial Language and Scale

This group identified two major aspects, not completely independent, to the topic of spatial language and scale. One is concerned with language for talking about scale, size, and detail. The second is concerned with how language may be scale dependent -- scale effects in the use and meanings of language.

Differences in the use of language at different scales would provide a basis for making cognitive scale class distinctions. Although not all group members completely agreed, it was maintained that most spatial terms in the lexicon of most national languages are scale independent. In other words, most of the terms used to talk about spatial relations, shapes, and so on are used at all scales. For example, one says "on the continent" and "on the table", etc. There are a few exceptions, and the group felt that there may be many exceptions. Later in the discussion, the group came around to note that ideal or prototypical meanings of spatial terms often do have typical sizes. So when people are asked to produce examples of a sentence that shows the meaning of "on" or "in" or "at", they produce examples that are at different scales. The scope of a given word usually covers all the scales you could talk about, but the core meaning may be at a particular scale. This is clearly a sort of scale effect.

Another issue talked about was that choosing the ground for spatial relations, choosing the reference object with respect to which you are going to locate something, is often scale dependent. So we would not usually say "my pencil is near State Street". There is something odd about that. You have to work for a long time to come up with the context that makes that a reasonable thing to say. Part of producing an expression that gives the location of some object is choosing what to reference it to. That is somewhat context and usage dependent, but there are scale issues too.

Another topic discussed for a while is the way measured distances are talked about in language, the idea of approximations. So the distance between Santa Barbara and Los Angeles is 92 miles. It would be odd to say that the distance is approximately 92 miles. But saying that it is approximately 90 miles would be common, suggesting the distance might be plus or minus 5 miles. If one maintains that the actual distance is 92.0 miles, then you have raised the question of the exact places between where it is measured for two extended objects. The idea of round numbers in translations between different measurement systems was also brought up. We might say it's about 100 miles, but we shouldn't say it is about 161 kilometers. So somehow there is the interaction between levels as approximations that are appropriate for expressing things. There is something odd about giving too much precision. In translation between measurement systems we do see effects of generalizing in one and then doing precise translation, which would be a problem for some machine uses. If we want to use precise metric information and then talk about it, we have to deal with some special rules.

The group discussed the fact that the "what" system has a spatial component that has to do with size and shape. To the extent that the cognitive system has separate "what" and "where" processing, both parts involve spatial information. "What" is about object identity, which involves size and shape. Dimensional terms like "tall", "thick", and "long" are applied somewhat differently by different languages and partially because of context. Does a couch have length when you are trying to manipulate it into a truck? Flagpoles have lengths when they are in unconventional positions but not in conventional positions. Most of this again seems not to be very size dependent.

The group asked what is known about the ages at which children grasp spatial language. They acquire metric terms later than nonmetric terms. Do children have trouble with small cars being bigger than large dogs? And then they catch on to the fact that some terms are relative to prototypes, while some have more absolute meanings. Bowerman and her colleagues have done a lot of work on certain equivalents of prepositions, and how those are generalized and distinguished. But it was not known by the group what research has been done on the development of the ability to use size or scale related terms, and at what ages people are able to comprehend these effectively.

Another topic of discussion was the term "here" and how it is scale dependent. It works at a variety of scales, but it seems that there are scales where it does not work. So you could say that someone is "here" and that might mean in this room, it might mean at the Upham Hotel, it might mean in Santa Barbara, or it might mean in Southern California. But it seemed as if it wouldn't reasonably mean an area that's midway between the size of Santa Barbara and the size of Southern California. Saying that someone is here might mean that they are in this place, and certain sizes, certain patches of geographic space, are places. One can switch among places of different sizes. But other intermediate chunks of geographic space are not places. It's not clear how people understand statements like one that was overheard at the meeting: "Mike Goodchild is here and he'll be here in a minute." This statement does not mean that he is here and is going to stay, but that he is here in town and will be here in this room in a minute. One participant offered a sentence using "here" at five different scales which was deemed interpretable, at least by some.

The group discussed language used to describe layouts or the shape of spatial relations when people describe a village or a house. Tversky and her colleagues have worked a lot on the use of perspectives in these descriptions, whether you give people a map-like view, and say the church is in the Northwest corner of the town, or whether you give an imaginary tour. It was suggested that the tour perspective wouldn't work for a very large space. One would never give a tour of the US or of the world. The group also wondered if there were systematic differences in how visually-impaired individuals might describe a tactile or auditory map, versus a sighted person describing an equivalent visual map from memory.

Finally, the point was made that qualitative linguistic descriptions are often more powerful or useful than metric or coordinate-based descriptions for dealing with imprecise representations or information of doubtful quality. One can say "the highway is blocked between here and Ventura". You can't draw a sketch of that without putting the block somewhere, but in language the position can be left completely indeterminate and still have the meaning of the blockage.

Breakout Session #2, Group 2
Children and Scale

This group discussed children's experiences in understanding size and scale. Like other groups, this group considered scale classes to emerge out of the integration of function and action with spatial size. The group also agreed on the importance of emotion and motivation in behavior, and the need for considering social and cultural context in research tasks. An example was raised of children perform very differently on spatial tasks in different social contexts.

A starting point for this topic might be recognition of the fact that children are small, the implications of which were discussed at length. But it's not just that children are small. With respect to the perspective from which children view the world, for instance, there is an interesting, almost U-shaped developmental curve. Infants are often at what is almost an adult-eye view, but then a few months later they get dropped down to the floor, and from there they have to work their way back up. Furthermore, the infant's eye-level view is largely a rear-view perspective on the world. There are interesting, developmentally relevant differences in how children experience the world. It's not that children are simply impoverished in their understanding, not simply that children are not as smart as adults are, but rather that they view and experience the world in fundamentally different ways. For example, children are always "getting into things", like dryers. This phrase should be taken seriously. What does it literally mean that children get into things? How does it affect children's conceptions of space and scale?

Golledge's Plenary Paper discussed the notion proposed by Granö in "Pure Geography" that three-dimensionality extends out to about 20 meters for adults, after which the world flattens. What would the distance be for a child? One participant guessed 7 meters. Would this distance scale proportionally to height in some kind of logarithmic function, or would there be categorical differences? The group also wondered about the effect of height variations and related covariates of mobility, leg dimensions, and reach. So height makes a difference, but height and childhood for the most part are highly correlated. They could be separated, however, insofar as adults vary in height. By analogy, there is some very interesting research on the effect of mobility on the development of spatial knowledge. There are a series of interesting studies where mobility varies independently of age because some children crawl earlier than others do. Or you can make it happen artificially by putting them in a walker. And you get real differences in their ability to integrate spatial knowledge as a consequence of when mobility happens in children's lives.

The group attempted to devise a scale classification for children. They tried to come up with a typology of the experience of scale at different ages and developmental events, which are only correlated with age. For young children, it is a question of visual/motor integration at scales around the body. There was an interesting debate about how well infants' reaching is scaled to object distances. One characterization of the data is that they make a lot of errors, but another perspective is that they don't. Young children have the idea that ground support exists as long as there is contact. By six to nine months, mobility begins, but via crawling rather than upright mobility. Do changes in modality of movement, for example the difference between crawling and walking, necessitate changes in concepts of scales or distance? There is some evidence that the answer to that is "yes". Infants that are confident crawlers up or down an inclined plane will have to learn that skill again when they start walking. So you can't just directly transfer motor skills to another scale. The group wondered if the same would be true for learning about large-scale space, contrasting space beyond immediate experience to space in the home. A child would have to come up with a whole new coordinate system or something like that to navigate in the outside world. The discussion was not that children at this age necessarily have a conceptual understanding of scale and distances. The question was simply whether dealing with or negotiating different scales learned at one size or in one modality would be transferred to a different size.

In toddlerhood there is an increased exploration of the home and outside the home, and one of the things that came up here was the importance of emotional relevance and social support. There have been demonstrations that children could use their mother as a landmark, and if they did so, they would perform better than with other types of landmarks. Another interesting phenomenon is "security of attachment". If you put an infant in the so-called "strange situation", children who negotiate it well are called "securely attached". Children who are securely attached are better able to use the home base, mother or father, for exploration of the environment. This stresses the important role of emotion.

The group next spent some time discussing the development of children's understanding and use of scale information, but by their admission, much less than could be said about this topic. This has been a research issue in the last fifteen years or so, how children develop an understanding of what scale is. It's not trivial, nor obvious. By age three, children can view scale models to find hidden objects. But that definitely does not mean they necessarily understand or have a concept of scale. Deloache has shown that these children could use scale models to find hidden objects, but children of two-and-a-half years old fail on this task because they don't understand that the small room is a model or representation of the larger room. If you take away the need to understand this representational relationship, then two-and-a-half year olds who normally search at about 25% correct will search at about 75% correct. The way researchers take it away is by using this magic shrinking machine that convinces the child that rather than the model representing the room, the model is the room. This really shows the importance of the "stand-for" relationship between a model and its referent.

Evidence that children don't understand scale comes from a lot of studies, some by Liben and Downs. Kids might say, for example, that a representation of a road on a map couldn't possibly represent a road because it's too narrow for a car to fit on. Or some children will make errors in understanding a map of Chicago; they will be able to pick out Lake Michigan but then claim to see fish in the lake. Other studies show that if you ask children to reconstruct a configuration of landmarks in a space, they get the configuration right but they don't scale it correctly. They just put the landmarks down.

Breakout Session #2, Group 3
Scale in Virtual Worlds and Cyberspace

This group discussed scale issues in various forms of cyberspace, including the Internet, World-Wide Web, and virtual environments (VE or virtual reality). One issue discussed was the spatial geometry of various cyberspaces. Netspace can be discontinuous, it can be many dimensions, or it can violate distance properties. On the Web, for example, one participant claimed that "everyone can be every one else's next door neighbor", though not everyone agreed. In cyberspace, one can violate principles of known geometries by, for instance, overcoming distance or network links by creating shortcut direct links at any time. There are attempts to map the layout of cyberspace by looking at keywords or links, adopting a multi- dimensional scaling strategy that builds distances based on the closeness of subject areas.

Some participants doubted whether the Internet or Web even has a geometry to its interactants (i.e. is even spatial). Others claimed that the geometry adheres to no known traditional geometry. One participant claimed that there definitely is a geography to cyberspace, calling it "geocyberspace". It has a distinctive geography to it, a network to it, based on your own traffic flow, your linkages, where you are trying to access. It can be represented as a visual image. Another participant claimed that most people don't care where they have been in cyberspace and so do not form any spatial representations of where they have been. Alternatively, a metaphor of spatiality has been used for cyberspace because of the naturalness of such a metaphor, but it is not necessarily the only or best metaphor.

Some interesting scale issues in VE and other cyberspaces were discussed. In real space, movement scales space. In a desktop or immersive VE, there is or can be a great mismatch between apparent speed and real speed. While it might be desirable to scale movement speed in an immersive VE to match normal walking speed, for instance, this need not be done. One step could be made equivalent to one mile. Some virtual tours of very large spaces, such as states or countries, would need this rescaling. In fact, technology has always played the role of shrinking the too-large or magnifying the too-small, as in Montello's categories of minuscule and gigantic spaces. But just as maps shrink very large spaces by creating somewhat fictional models, virtual models may have limited utility because they would not have all the properties of the real thing. A model of an atom being virtually explored by chemists was an example given. However, the virtual exploration of atoms has apparently prompted new ideas and ways of thinking that have born fruit. But someone will always have control of what is depicted in a virtual world -- it will never be a reality independent of human conception or intent.

Teleportation in VE has interesting scale implications. It potentially makes a virtual world appear scaleless, at least at first. The putative impatience of people online was offered as support for the disappearance of scale or at least distance. The different access or response speeds of different Web sites was offered as continued existence of distance friction and scale. By the same token, the idea that one instantaneously hooks up to the global by getting on the Web is a bit of an illusion. One participant opined that virtual worlds should be scaleless and multidimensional in order to receive their full potential. However, others thought that perceptual/cognitive limitations such as attentional capacity and visual capacity could still create scale effects.

Several different yet simultaneous "spaces" of cyberspace were identified: (a) the real space of the physical network, with server locations, terminals, etc., (b) the information space of network connections, (c) the apparent space created (or not) in the mind of users while "in" cyberspace, and (d) the real space of entities contacted on the Web (such as the location of a museum found on the Web). There would be distinct geographies and scale issues for each of these spaces.

There have been and continue to be many attempts to apply what is known about navigation in real space to navigation in cyberspace. For example, creating virtual landmarks, metaphorical landscapes, or even applying Lynch's typology of landmarks, nodes, edges, paths, and districts. Researchers have asked whether route and survey knowledge exist in digital worlds (assuming they exist in the real world). Can one provide hierarchical structures or overviews of cyberspaces to improve orientation? The group considered differences and similarities between navigating in real space and cyberspace, such as getting lost and emotional reactions that result from that. One participant specifically focused on orientation in VE systems, which are in many ways more similar to real spaces than are other cyberspaces but still allow such violations of geometry as dynamically altering one's size or scale. The work of Pauch was cited as a good example. He uses a virtual map within a VE, so the user is in a VE holding a virtual map. Users can see where everything is, all the different rooms. If they want to go to a different room in the environment, the map gets bigger and bigger, and users fly into the map. The map gets bigger until it becomes the environment, and then suddenly the user is standing in the new room with a new virtual map.

Virtual spaces promise new freedom of movement, but this is not something that people adapt to right away, if at all. Some research has shown that people put expectations about gravity and other normal physical laws on virtual spaces, even though they need not. Specific examples were cited, such as people's reticence to step through objects in a VE. These expectations hamper performance in VEs. In his book "Cyberspace, First Steps", Bennett suggests that constraints need to be put on the design of virtual worlds to make them familiar, even though the technology does not require them. Some of the limitations and difficulties people have in navigating cyberspace may be due to its newness for most people. It was suggested that children being raised with the technology will use it more easily, more fully to its potential. Itṡ a matter of understanding new metaphors. The example of cinema was raised; when it first came out, people ducked at oncoming trains in the film, but we don't duck any more. This view was countered with the fact that humans have an evolutionary past and live in a real physical world that is not done away with so easily.

The influence of cyberspace on social and communal scales was discussed. Cyberspace is advertised as a way to bring the world together. But it supports fragmentation insofar as nearly every small interest or service can find a market or audience, things that heretofore required large cities for their existence. This will destroy many traditional businesses. The question was entertained as to whether cyber-economics would destroy traditional geographic and economic concepts of market thresholds, range, hierarchy of central places, and so on. However, these concepts will still be relevant because distribution is still material (without teleportation), at least for food and clothing and other material goods. Yes, technology is changing some distance relationships, as it always has, but it will not completely destroy them in the foreseeable future. As long as humans cannot live on information alone, but require material pizza and beer, distance will still exert its influence.

Breakout Session #2, Group 4
Reference and Coordinate Systems

Reference systems are systems for encoding or expressing location and/or orientation. Where is an object or feature in the world? Which direction is it facing? The answer may be precise or imprecise, it may be complete or partial, it may be context-dependent or independent, it may depend on the perspective of a viewer or speaker or not, it may support inferences about other objects -- but in all cases, location and orientation must be specified relative to something.

A variety of coordinate and reference systems were discussed. Coordinate systems were seen to be a subset of reference systems in which location is assigned metric coordinates. Latitude and longitude (lat-long) is but one of the many coordinate systems available. People frequently use reference systems that are not coordinate systems. Language, for instance, typically encodes object locations in imprecise or qualitative ways. One's body (or part of one's body) or external features are often used to organize location. Sometimes these external features are relatively local, such as a tree or a building. Sometimes they are relatively global, or operate over large areas, such as the mountains and the ocean in Santa Barbara. Cardinal directions are used in some places; one participant suggested they were more common in the U.S. Midwest.

Individual differences in reference system use were discussed. Some people can read the sun, use cardinal directions, or even lat-long in informal situations -- may other people clearly cannot. Some participants claimed that no one uses lat-long or systems like UTM (Universal Transverse Mercator) in informal situations, but others insisted they do. Street grid systems were proposed as an example of lat-long, or at least like lat-long. Some systems were thought to require special training for their use. Scale was agreed to be an important determinant of which reference system is used. Smaller spaces are more likely to involve egocentric frames. An example was given of thinking about the location of Los Angeles vs. Hanoi -- the latter requires thinking about the earth's curvature. One view was expressed that changes in technology could have us carrying around GPS receivers and possibly talking about small-scale locations in terms of lat-long. In cartography there are rules that prioritize which feature is moved first. Does this hierarchy also appears in a cognitive sense? When you are orientating yourself, is there a process that prioritizes the features that you use?

Room spaces were contrasted with city spaces. One participant suggested that a person can certainly locate and describe things using a city grid. But if the person is given a problem that fits a view of the space that the person had experienced directly vs. a view of the space that had not been experienced directly, the person will be faster and more accurate on the former rather than the latter. That says that space is encoded in some kind of egocentric manner. Conditions under which an egocentric or absolute frame would be used were discussed. An important question was how egocentric knowledge could be transformed into ego-independent knowledge.

There was a fairly detailed presentation of studies conducted by one of the participants. These studies use methods similar to those reported by McNamara in his Plenary Paper. Subjects indicated the locations of objects in a room faster when their imagined heading was the same as the heading of a preferred alignment defined by the axes of the testing room. Some similar findings were reported with subjects imagining themselves in the center of a town, the street orientations providing reference axes. Conclusions were made about the reference systems people use to encode spaces.

The egocentric system, in which location is relative to one's body, was deemed biologically fundamental, an evolved system that supports a person's ability to function in the world. Reference systems in cyberspace and virtual reality were discussed. An egocentric system was thought to be likely here. In immersive VE, people will probably use the same systems they would in a real environment. The question of more abstract digital worlds was discussed. Defining space in situations such as the Web, let alone scale or reference systems, is a difficult issue. As in
an earlier session (Breakout Session 2, Group 3 on Scale in Virtual Worlds and Cyberspace), the degree or way in which the Web is spatial was debated.

Breakout Session #3, Group 1
Geographers' vs. Psychologists' Scale Concepts

A recurring theme at the meeting was the way disciplines at the meeting, particularly psychologists and geographers, conceived of scale (and space) differently. Although the group asked at one point whether in fact there are differences, they ended up feeling pretty confidently that there are. The notion of discrete scale classes, that at least some psychologists favored, vs. continuous scales, the way geographers tend to think of scale, was one example. Both disciplines agreed that some activities or processes may be scale-independent and some may be scale-dependent. It is likely that they do not agree on which processes fit into each class (they would not necessarily be aware of each others' sets of relevant processes, of course). Another case is the spherical earth but the apparent flatness of local space. Earth processes occur on a (near) sphere, an aspect of space which is not often appreciated by psychologists, nor is it clear that it should be. Another participant mentioned that the richness of strategies people actually use to reason about real-world spatial problems may not be recognized by much psychological research.

Much of the discussion focused on differing conceptions and uses of maps by the two disciplines. For a psychologist, a map may be primarily a spatial or graphical entity, but for a geographer, the map contains information about earth processes, human and physical. The motivations, some political, behind creation of the map is more prominent to a geographer/cartographer. Psychological work on pattern perception could be useful to those trying to understand maps, but maps are not just graphical patterns, they are representations of earth processes. This is not reflected in psychological research on maps, and is responsible for some of the strange maps that psychologists create, according to some group members.

Psychologists use maps only so much as any layperson would, though they do research on how people understand and use maps. Psychologists most frequently use maps as stimuli to study spatial cognition, not in order to understand maps per se. Psychologists, with rare exceptions, are not aware of the wide variety of map types and their uses. The maps in their research are frequently very simplified and lack such elements as legends, scale bars, and compass roses. This implies to some geographers that the maps of much psychological research are not really maps (Figure F). Conversely, geographers usually have a very complex and rich conception of space that depends on sophisticated coordinate systems. Such a conception is much more elaborate than that used by laypersons in most situations. This implies to some psychologists that the models of human spatial reasoning in much geographic research are inaccurately detailed and sophisticated (Figure G). But how detailed is too detailed (Figure H)? At this meeting, maps were constantly described as situation-specific models of parts of the world, not as carbon copies of the world. There are all kinds of different maps. One participant complained that when psychologists go and, for a specific reason, construct a map in a specific way, they are told that their "maps" are silly, not good maps. If there are so many map types, and none have the status of privileged truth, why aren't those used by psychologists just as valid for their purposes as other maps are for their purposes?

One of the most important reasons for different approaches to space and scale by the two disciplines was thought to be their different research goals and interests. Geographers may be more interested in overt process and structure, such as spatial behavior, while psychologists tend to focus more on the underlying cognitive structures and processes as an end in itself (at least cognitive psychologists). Their purposes do tend to be somewhat different, even when they focus on very similar domains of human behavior. There are spatial problems of interest to psychologists and not to geographers, such as object manipulation. There are spatial problems of interest to geographers and not to psychologists, such as locating industries. There are spatial problems of interest to both disciplines, such as human navigation. Navigation has some special characteristics, such as the motivations it creates in map users, that are not present in other map tasks, such as representing the distribution of typhus. Navigation should not therefore be considered a generic model of a map task. It was argued, however, that most laypeople care about maps primarily for navigation.

The degree to which the approaches of each discipline can or do inform the other discipline's work was discussed. The methodologies and materials of the two disciplines differ, and there was discussion of the ecological validity of psychological work in laboratory settings. Psychologists traditionally do not focus on scales bigger than rooms, and geographers traditionally do not focus on scales smaller than cities or neighborhoods. The relevance of the work at some scales for work at other scales is an important issue. Does work on a tabletop apply to a city? The task involved was seen as one important factor in making this leap. But even geographers in the room did not agree on whether certain scales such as the tabletop could be validly used to address geographers' spatial questions. The need to integrate information over time at certain larger scales was emphasized as a possible basis for rejecting the relevance of work at small scales to some questions at larger scales. Although some research was discussed that argues against specific aspects of cognitive scale differences (particularly orientation specificity), that does not mean that the use of pictures or small object spaces can validly be used to study all aspects of spatial cognition. Both disciplines came to agree on that.

The group came up with a list of examples of processes that they believed were either scale-dependent or scale-independent, or that influenced processes at different scales similarly or differently. Scale-dependent included integration of knowledge over time, navigation. Scale-independent included orientation (static views), remembering layout, and the general cognitive system (e.g., working-memory constraints).

Breakout Session #3, Group 2
Research Methodologies for Studying Scale

This group discussed methodologies for doing research studies on scale effects, particularly in cognition. There was a great deal of discussion on the effects of various aspects of context on research methods and their implications. How do we contextualize our methods at different scales? How does that contextualization of method create scale? How do our methods relate to size, such as when we move from the desktop to the football field? There is also an issue of shape, shape of a contained or bounded space, the context effects of a square vs. a circle, for instance. Are there edge effects here? What about the pattern in unbounded spaces? In some senses, the natural outdoor world doesn't have walls. If we move relative to the horizon, the horizon moves with us. Also, different sized spaces create different contexts, for example, emotional or political. How do objects and events in spaces engage us, and do the laboratory methods engage us in these ways? Children may get engaged differently by some of these tasks than do adults. What would happen when doing research with children if you introduced characters like X-men as your objects rather than lumps of wood? There is scale implicit within the types of questions that we ask. Think of a park with a path through it. How big is the park? Is it a city park or a National Park; is it a path or a road? How does the way we present research stimuli to subjects influence the judgments we ask them to make? Figures I and J show two versions of the "road goes through the park."

There is a difference between the approaches of psychologists and geographers (as discussed in Session 3, Group 1). The tendency for a narrower focus in experimental psychology could make it difficult to step back and generalize. This might be seen as a problem of discourse, different ways of knowing. Certain terms are used differently by different disciplines. It is a question of finding out where the commonalities are. How do you maintain or lose validity and replicability when you change the scale of methods to move into large-scale environments? Is it necessary to lose control in larger environments, which leads to a certain disbelief or disrespect for the studies? A psychologist would want to perform an identical experiment where everything about the testing environment was identical except for size. If you had a difference you could then say you have had a scale effect. There is the real hope that research with virtual environments can combine control and ecological validity, allowing a variety of scales. And though most psychological studies are done in smaller scales, not all are. There is psychological research with campuses, neighborhoods, cities, and so on. One participant expressed the view that most cognitive research is excessively positivistic, and excessively empiricist in that it lacks theory. Contrary to this, the view was expressed that all of the research we had been discussing did have theoretical bases. Which would mean it is empirical rather than empiricist. Are there methods that are not empirical?

There are several different taxonomies people have offered for cognitive scale classes. One of the breaks of scale that occurs in all the models is between large and small. Small is where you can perceive things from one vantage point without having to move through the space; large requires locomotion through space and inference over time. But the breaks between scale classes may be quite task specific. Mode of locomotion affects scale classes. They are different if you are driving rather than walking. If you are driving, you need information a couple of blocks ahead, but if you are walking, you only need the information one house ahead. And the kinesthetic information is there in one case but not another.

Breakout Session #3, Group 3
Scale in Formal/Computational Modeling

This group began by discussing the definition of a formal model. Formal models involve well-defined/specified entities and operations for acting on the entities. They have axioms, which allow one to prove many statements about the entities and operations. Furthermore, formal models allow for explicit and provable statements about the derivability of new conclusions (theorems), and the complexity of these derivations. Formal models can be applied to help understand human spatial reasoning and the computational behavior of automated spatial reasoning systems. Geometry provides a good example. It is a branch of mathematics with a tradition over 2,500 years old. "Spatial calculi" in artificial intelligence (AI) provide recent examples of computational geometry, such as approaches by Cohn and by Egenhofer.

Formal and conceptual models were distinguished. Conceptual models of spatial reasoning are the focus of cognitive geographers, psychologists, AI researchers, and others who are interested in the spatial behavior of organisms (including machines). Formal models allow conceptual models to be mathematically characterized in an explicit way. This allows for explicit and more powerfully testable statements about the behavior of organisms in particular settings. It also allows computer simulation/realization.

Formal models of space are generally scale free. More precisely, formal models are rarely committed to the concept of scale. They are designed without explicit consideration of scale. Therefore, they may be used at any scale a researcher wishes to apply them.

But scale becomes critical in implementation and use. Implementation can be inter-scale, focussing on structure, or intra-scale, focussing on process. The former includes issues of vertical scales, choices of views, and a concern with applicability across scales (such as wind tunnel research wherein certain features of aerodynamics apply only at certain scales). The latter is concerned with horizontal scale and is extremely task dependent (such as display choices on a map).

Scale comes into play when more than one level of representation is taken into account. Two different types of models, or situations, were discussed. When the levels are procedurally independent, there exists mappings between the represented levels which must deal with some scale-relevant constraints. For example, regions may be treated as areal or point-like. A second type of model has representations linked in hierarchical structures, that is, objects from different levels are connected with links. These two types are researched (in cartography and spatial analysis, for instance), but are not well understood from a formal perspective.

Usage usually usage locks in scale in formal models, but not always. It depends on the spatial/temporal relations involved. In any case, most formalisms apply at multiple scales, and context drives usage. Formal models are often at odds with empirical models. Or they often ignore each other. But the two can usefully inform each other, as in the example of ecosystem work.

Breakout Session #3, Group 4
Time and Scale

This group discussed temporal issues relevant to scale, including issues of finding the appropriate time scales for analysis, and deciding on the best way to depict or externally represent time scale (in maps, animations, etc.). Examples of ideas about types of time include work by Sacks and by Couclelis. They make distinctions like linear time, sequence, duration, cycle, and temporal landmarks, reference points of time. There is the past and the future; there is time as a process versus time as a framework or container.

Four types of time relevant to research in geographic information were distinguished. First, there is the time of the phenomena. Then there is the time of the data, which is our attempt through measurement and quantification to capture the temporal properties of the phenomena. Third is the objective temporal parameters of external representation. So for instance, you make a map or an animation, and you make a decision about what time intervals should be shown. A fourth time issue is subjective time or the perceived conceptions of time that come from viewing the external representations. It is important to consider research on all of these, as well as interrelationships among them. There is clearly an important and central relationship between the objective presentation of temporal information, and the perceptions and cognitions people have about that data.

Temporal resolution and aggregation was discussed, analogous to spatial resolution and aggregation. There is a temporal MAUP (modifiable area unit problem). One could have to deal with both a MAUP and a MTUP, or a combination of both of these, a MATUP(!). If we consider temporal resolution separately from spatial resolution, we may run into some seriously misleading things. It may be the right thing to characterize the unit as spatio-temporal, but that makes the problem a lot harder. There does need to be an attempt to simultaneously look for spatial and temporal scale. Just as you might use pattern recognition, neural networks, or machine intelligence to search through a large number of possibilities in order to find the appropriate spatial scale, you may be able to use automated methods to help you search for appropriate temporal scales.

The group discussed the visualization or external representation of temporal information. The pure case is when you use a temporal visual variable, which means a representational symbol or semiotic code which is visually perceived. For instance, movement can be used as a visual variable to represent dynamic phenomena, as in animations. That is very direct -- if you want to show change over time, use movement. There are a few early examples of cartographic flipcharts to show dynamic data. Tobler has written about using static visual variables such as arrows to represent dynamic phenomena. You also have the possibility to use movement as a visual variable to represent either correlates of time, such as temperature or daylight cycle, or you can in fact use it to represent non-dynamic phenomena. For instance, there have been suggestions to use movement to represent uncertainty in spatial data. There was some belief expressed that this might only work to a degree, or even be misleading. Movement can also be useful as a means of gaining access to multiple perspectives on data rather than as a semiotic vehicle, such as when a three dimensional object is rotated in order to see its shape.

The group discussed animations. What about the relationship of animation time to phenomenon time? You speed it up or you slow it down or you show it in real time. It is pretty much true that maps shrink space. If they blow it up, we tend not to call it a map. In the case of animation, if something is really slow we usually speed it up. If something is really fast, we slow it down in our animation. There are cases where the speed of the representation and the speed of the phenomena are the same. There wouldn't be any need for temporal scale translation. The fundamental question concerns what you extract from animated displays. There is a huge opportunity for research on this question. How effective is the film 'Powers of Ten'? The little clock face used did not indicate twelve hours, which is the prototypical clock face in this culture. And it did not have a constant unit, such as when one revolution of the clock hand sometimes meant ten seconds and sometimes meant some other unit. That was an attempt to try and visualize what is very difficult to visualize, but it may be quite misleading. One person questioned whether the clock gave any information or was just a spinning dial.

There are many choices when you make an animation. What are the start and end points of the temporal data that is shown? What should the temporal interval be? How many temporal intervals? How fast should it be shown? There is a great deal of research to be done asking these questions with respect to the message the user takes from the display. There is a need to communicate temporal intervals and speed to people who are viewing the animation. U.S. television stations give weather reports that show satellite pictures all the time of clouds moving over but with no information as to whether the viewer is seeing ten minutes, one hour, six hours, or whatever. It would take a very meteorologically educated person to understand this implicitly. In Germany they show this with a little clockface symbol. There is some existing literature on cinematic perception and animation in the sense of cartoons. The time delay that produces a perception of jumping movements, for example.

The design of interfaces was discussed, including such issues as slider bars, brushes, and icons. When you make an animation, it is desirable to have smart defaults, with respect to the speed and any intervals. It is also desirable to have flexibility of user control. One participant characterized this as closed-script/open-script. A closed-script is something that runs until it is finished, once it is started. An open-script would allow you to pause, stop, back up, increase the speed, or in some way interact with your data or change its content. There are lots of possibilities to having a user profile. However, there are great differences among individuals. With user profiles, you can characterize certain subclasses of users and provide an interface that is tailored to their needs. When you consider the notion of expertise with displays, there is the domain expertise and then there is display or visualization expertise.

User tailoring is a very dynamic problem because as people get familiar with the system, their expertise will change. The profile needs to be established at the beginning and then updated. This has been discussed in the HCI (human-computer interface) community for a long time. Also, you don't have to assume that the display works best if you can go in there completely untutored and then understand it. When you talk about optimizing a representation system, a semiotic method, you don't just consider when naive inexperienced people view it. You have to make it so that it communicates efficiently to a wide variety of users.

One participant questioned the notion of a completely open-scripted display. Nothing is completely open-script, somebody has to set the parameters beforehand. A lot of people recognize these things are bad because they don't give the user options, but on the other hand, it is not good to give users too much option. That's one reason we have so many bad maps and graphs. Computers do it, and you just point and click. People need to be given more intelligent structure and default.

Research suggests it is difficult to integrate information with static displays where information is distributed over space. Although we think people see the whole map at once they attend to different parts and then fit it together temporally. In an animation, information is distributed both temporally and spatially. But we can only attend to one place in space at one time. Let's say we are looking at a weather map, there is a weather pattern happening in California and another one in Florida -- you can't attend to both at once. That's why it is really important to have an interactive control. A static map can present a lot of information, but you have all day to look at it. Disney's principles of animation suggest primary and secondary animation. For example, a dog running across the screen would be primary, and the secondary would be that the tail is also moving. This reinforces the primary. There is a body of work in AI, in cognitive simulation, where the notion of time is purely qualitative. The interesting points in time are when something changes. With animation there is another measure that is coming along now, sound and film clips.

If you take an audio tape, you can run that back and forth. The rate at which you run the tape will change the pitch. So in other words the way you are viewing the data in a technical way actually changes the nature of the data and the way that you perceive it. Is there a case for animation research that doesn't consider the data to be always the same no matter how it is presented? In other words, would the data be changed depending on the speed at which it is viewed?

You can look at a map all day, but what happens if you look at an animation all day? Would there be any difference between the two modalities in terms of information output? A parallel might be between experiencing an environment by walking through it and from a map. With animation there is the possibility of directing the viewers' attention to something. Sometimes you can have spurious change take place. You can have the equivalent of cartographic line generalization happening in time where we can take out spikes. Often animations are very busy. There are some limitations on the user, such as attentional factors, working memory limitations, etc. It may be very useful as propaganda, but sometimes you may want to take away from it one image. You can have an animation linked to a static summary graphic. With a weather map you can use the sound channel to bypass the need for a clock, such as a narrative or sound clicks. Otherwise we overtax one modality. One thing the visual modality is good at is picking up correlate activity in space. In brain imaging now it is extremely common to animate which areas of the brain are active in response to some stimulation over time. This is an area where cartographic scale does matter. If the display is limited to a computer screen or similar projection, you are limited to how much detail you can display. We can pan and zoom, but we can't show detail and the synoptic picture at the same time.

Breakout Session #4, Group 1
Scale in Action-Perception Pairings

This group discussed ways that scale emerges from perception/action systems and the implications of scale for perception and action. Scale is a relationship of relative magnitude. Perception is the means of acquiring information about the world. Action is the means of responding to events in the world. These are similar to the more traditional terms of sensory and motor systems, but perhaps reflect a conceptual focus more on behavior and knowledge, rather than physiological receptors and effectors. To some, perception/action reflects a Gibsonian theoretical framework (J. J. and E. J. Gibson) of ecological knowing, affordances, and direct perception. Some in this group favor that framework, others do not. The discussion did not constrain itself to any Gibsonian interpretations.

In fact, separating perception and action is somewhat questionable. Perception and action are in a sense part of a single integrated system of making contact with the world. Perception informs action, action informs perception. The two have implications for each other. One acquires information about space, for instance, by looking, listening, and walking. Alternatively, one could say that perception can substitute for action, or vice versa. This does not happen equally at all scales.

There was an extended discussion of how the perceptual systems might scale space. The function of different perceptual modalities, such as vision, determines the information that can be extracted about the world. The different senses provide somewhat redundant information, at least at some scales. The different senses are suitable for picking up information at different distances -- vision is traditionally understood to be the most effective "distal" sense, while touch is effective only within one's reach. Audition (hearing) would be intermediate. Landmarks in the environment help to scale space. Longer distances are perceived in "cluttered" environments, but these are usually visually perceived landmarks, so that blind people would not scale space in the same way. Work such as that by Goldin and Thorndyke compares environmental learning by direct experience vs. a video. In information displays, different senses can be used to acquire information that they would not normally be used for in the real world. Data sonification or tactile/haptic communication are examples. One could have a temperature map wherein different auditory tones are played when the hand goes across different temperature regions. Or one could use haptic or auditory information to communicate navigation information. These "cross-modal" applications are not easy; perceptual modalities are designed for certain functions and not others.

Actions also serve to scale space. Different actions can be performed at different distances -- there is reaching scale, walking scale, projectile scale, and the space beyond these. This is a classic basis for distinguishing cognitive scales, or "action spaces". It is one of the main reasons that there has long been a distinction between room spaces and city spaces, for instance. Action scaling has implications for function, what can be done or what is the purpose of behavior at different scales: picture space, object space, room space, local environment, global environment.

One of the participants discussed his work identifying action abilities in movement therapy. Something like 250 different activities are used in movement therapy. This person and his colleagues are trying to identify and catalog everyday activities that have implications for the scaling of space. An interesting example was given of surgeons, whose skills deteriorate when they go on vacation for several weeks. Special motor exercises can bring them back relatively quickly. The idea was expressed that most psychological research ignores everyday kinesiology. Another example was airline pilots, who lose skills as do surgeons, even though they deal with space at different scales.

How does the use of different motor systems and locomotion modalities affect spatial learning? Walking vs. running vs. biking vs. driving are examples. It is commonly believed that this is quite important, though there is not much evidence for it other than intuition. A well-known study of mental maps in Los Angeles found differences according to the neighborhood where subjects lived, which was interpreted to reflect differences in activity space and modality related to socioeconomic status. Other influences on scale perception and cognition were discussed. Motivation and emotion is different in different spaces. These have implications for time perception, effort, and attention. The perception of risk or danger varies. The possibility that these influence distance estimations has been investigated. One participant spoke about the fear he experienced upon mistaking a hare for a polar bear in the Arctic. Aesthetics are also different in different spaces.

The group discussed the relationship of perception/action to spatial measurement systems. One participant has investigated this interesting topic rather extensively, examining literature on spatial units in different cultures and historical periods. Most measures of length used at room scales are in inches and feet, yards and so on. These are related to body part sizes, such as fingers, hands, feet, and height. There are no area measures native to the tabletop world. The area of manipulable object spaces uses the square of a length measure. Distance measures in larger spaces are related to effort and activity, such as a day's walk, typically activities in outdoor spaces. A league is 1 hour's walk at a good pace. There are lots of area measures in geographic space, how much you can plow or ride around on horseback in a given amount of time. Another is the amount of seed that can be sown in an area of a certain size. Furthermore, length measures are very multi-modal, touching, reaching, standing, etc. Volume measures frequently relate to effort, such as a bushel reflecting the weight that can be carried in a certain time span. A book called "The Measure of Man" discusses much of this. It describes how measures became regularized in the 16th century. For instance, the legal "foot" became the average foot length of the first 16 adult men to come out of church on Sunday. The planet was used as a reference for metric units; 10 million meters was the distance from the pole to the equator. These are events in European cultures, and it would be valuable to extend these analyses to other cultures.

Technological advances have increased the range of human mobility and action, and consequently the scaling of space. The automobile and the airplane are examples. In virtual environments, one might not have the normal proprioceptive cues to motion but only visual cues. Research is showing that translatory motions can be communicated effectively with vision alone, but not rotationary movements. Thus, people can orient with respect to translations in a VE quite well, but have trouble updating turns and corners. The example of virtual "fly-overs' was discussed. Scale classes might be changing as technology gives us different perceptual/action access to spaces of different scales, including the very large and the very small. The group considered how easily people will be able to grasp things outside of the "normal" scales of perception and action from evolutionary and life history.

Breakout Session #4, Group 2
Scale in Human vs. Physical Processes

In this session, participants discussed geographical processes in the human world and the physical world. The focus was on the role of scale in these processes, and how that role might be similar or different in human and physical processes. The group began by listing human and physical processes, recognizing that many processes are both human and physical, without a clear boundary line (e.g., fire, pollution, floods, disease):

PHYSICAL	HUMAN
erosion	navigation
deposition	urban growth
seismic or volcanic activity	information flow
landslides	agriculture
weather/climate	war
biogeochemical cycles	commerce, trade
hydrology	industry
soil	transportation
	migration

Some processes are human at one scale, biological or physical at another; scale helps define which category it goes into. An example would be agriculture. The group also recognized that other distinctions might be better for understanding scale and process, such as biological vs. nonbiological.

How is scale related to these distinctions? Multiple scales operate in some processes, including nested scales of process. Scale of process is distinct from complexity of process, though scale may matter more with heterogeneous processes. There is an important distinction between scale in measuring vs. in representing process. From a cognitive viewpoint, it is interesting to note that cognition is information flow, and that communication is cognitive. Also, maps serve to cognitively interface between scales.

It was thought to be generally easier to define or delimit scale for human processes; there is more likely to be a limited scale of operation for human processes. The individual is the smallest scale or indivisible unit for human processes, but this easily conceived scale unit sometimes misleads understanding of human processes (disease as carried by individuals vs. societies, for instance). Smaller than the individual (neurological) becomes physical. Furthermore, human processes have more easily defined discrete units at different scales (individual, family, social group, city, nation). The exponent in gravity models reflects scale of human process. With respect to temporal scale, it was thought that human processes are frequently less regular, especially beyond the year unit. Human processes cannot operate beyond the scale of the evolution of humans or the development of particular traits or practices -- often not even that far.

The group believed that human processes usually operate at larger cartographic scales, that they do not extend to continental or planetary or universal scales. Further, physical processes are usually mapped at smaller cartographic scales. An example comes from Britain, where 100%

digital information coverage exists only at smaller scales, the urban areas are mapped at 1:1,250 and 1:2,500, while rural areas are mapped at 1:10,000.

Is there a physical equivalent of the human concept of "economies of scale"? Objects and events must be large enough to survive (critical mass). Examples are landslides, seismic events, fish schools, insect colonies, and epidemics (some epidemics are more human, others more physical).

Breakout Session #4, Group 3
Scale in a Digital World

Participants in this session discussed scale issues in the context of digital geographic information. What is different in this context, what is the same? The distinction between making maps vs. databases is important. There are digital, visual, and virtual worlds, auditory virtual worlds, textual MUDS, in-vehicle navigation systems, hypermedia systems, and the Web. How does one reference scales in those environments?

The group discussed the notion that scale disappears or is in some sense irrelevant in digital worlds, as suggested by Goodchild's Plenary Paper. It was maintained that from a psychological prospective, there is a lot of appeal to the idea that scale as traditionally understood by cartographers or geographers is really meaningless in a digital world. What users see is related to what they want to know. When people use a digital database, they want to know whether they can see a particular lake or river. They don't care what the scale is in the traditional sense. Another participant stated that this is not an issue of scale but of resolution, the unit of observation, the unit of meaning. Even in digital world, however, there is a relation between resolution and scale.

One could be dealing with multiple representations rather than scaleless imagery. As people learn to zoom in and out, and move around, they form their own representation of the scale. The presumption may be that scale is infinitely variable and is under user control in the digital world. Whereas we have traditionally had to have maps with fixed relative fraction errors. You have this scale or you have that scale. With photography you can zoom in or zoom out infinitely, but with digital map based products you should be able to do this as well. This will require automated generalization, not just a set of multiple fixed scales. Scale in virtual worlds was again discussed.

The group discussed user expectations at length. An adult sitting down in front of a database who wants to do a siting task will be faced with some of the same scale issues as a child trying to do a school report. They will have expectations. As they work with data at a particular scale or resolution, there will be certain expectations about what is there. When a forester looks at an aerial photograph, he or she has expectations about the processes that are going to be seen. The link between an internal cognitive model and an internal digital model in the system is what drives the cartographer. As GIS and remote sensing are introduced into K-12 education, expectations will change.

As in other sessions, the purpose or function of an image or representation was seen to be critical. What is the user trying to do with the image? Scale and use are related, because you use an image for a set purpose. For instance, when trying to determine the scale at which a process should be analyzed, one tries to find a pattern that is expected, a pattern that is robust. One may use maps but is looking for patterns in the data, not looking to make the best map.

This group also discussed the need for multiple entry points for various levels of sophistication or other user characteristics. Children will want to use digital data in one way, in a highly symbolic standard map format. You can also have entry points for a graduate student working on a thesis. Presumably, you have a common database that is accessible to all those people. Communicating scale to the visually impaired through sound maps is another example. You can use some kind of verbal method, the screen can be labeled as a room or a building, or that one inch is 100 meters. Another way is some kind of auditory scale bar or haptic device (see Breakout Session 1, Group 4).

There was an extended discussion of scale and detail in linguistic descriptions of space. The last thing you would want in an in-vehicle navigation system is a map, according to one of the participants. You want turn left or turn right. There could be a lot of detail in the database that is not needed in a given instance. What level of detail do you present linguistically? One participant discussed the example of directing people to her house. There are certain cues in the environment that this person uses. This is an issue of scale as well, of how much detail you put into a representation.

Finally, map generalization was discussed. Another conversation took place about the degree to which map generalization is or should be like continuous image zooming (see Breakout Session 1, Group 2). A map is an artificial abstracted reality, whereas a photograph isn't.

Breakout Session #4, Group 4
Equivalent Realities/Internal and External Representations

This session discussed issues of real worlds, externally represented worlds (maps, VR, etc.), and internally represented worlds (worlds as perceived or cognized). A great deal of the discussion focused on the distinction between the sensory simulation vs. the cognitive experience of reality created by external representations, apparent reality vs. believed reality. External representations can create an illusion of reality that may trigger many of the same emotional and behavioral responses as reality, even though they are understood by the user to be illusory. Sensory stimulation can be similar in reality and virtual reality, eventually perhaps even identical. Even when sensory experience is the same, the experienced reality may be different, such as when a person knows he or she is being exposed to a simulated reality, even though they cannot discriminate that from any sensory information. It was questioned whether the suspension of disbelief to external representations is willing or unwilling. And this is no new phenomenon; the example of crying when viewing a film that you know is not real was offered.

The example of an astronaut looking out the window was discussed. The view could be of a real world or of a simulated world, and the astronaut would not necessarily have any idea of the difference. You could fool the person into thinking that they are in reality, so you are having an equivalent experience perceptually and cognitively. One participant argued that you would not be dealing with a representation in this case. Deloache's work with children's difficulties understanding a model room as a representation for another room was again cited. All of this suggests that you must realize you are looking at a representation in order to have a representational experience. Another participant thought this implied that everything is both itself and a representation of itself! An interesting research question concerns what constitutes a representation for a human being, what properties define when something seems to be a representation.

One participant urged that we distinguish between "re-presentation" and "representation", that you can't have a precise re-presentation. The whole reason for representation is to highlight something, to present certain information to tell a story, and every representation does tell a story. External representations are often (if not always) intended not as full simulation but as augmented, distorted, stylized, filtered, or generalized copies. This is a well-known truth about traditional maps. It is interesting that humans can actually represent reality even when they are getting a very schematic version. They fill in the blanks.

All external representations are controlled by their creators, though they may give the user an illusion of control. This is a negative aspect of the digital revolution: an illusion of freedom that is really a way to exert control over access to real worlds. Perhaps in fifty years from now, we will be born into a virtual reality that somebody creates, and somebody would design our entire experience. To a certain extent that happens already. Every map is a propaganda map.

IV. Research Questions

The final session of the meeting on Saturday afternoon was a Plenary Session in which the whole group contributed and discussed research questions on scale and detail in the cognition of geographic information. In some cases, these overlap with the initial research questions included in the Call for Participation (listed in the Executive Summary above). The scale of these research questions varies. Some are very specific, such as might guide a masters thesis or single study research paper; others are broader, and might more accurately be called research programs. Some of the questions are quite novel and probably have never been researched before; others have been addressed to a certain extent by previous research (some by participants at this meeting), though were perhaps examined at this Workshop in some new contexts. There is no particular basis for the order in which these questions are listed.

1. Can spatial scale be effectively communicated through modalities other than vision, and if so, how?
2. Can scale dependent and scale independent processes in spatial cognition be differentiated and characterized?
3. Are there circumstances in which locomotion through an environment will generate orientation-independent representations?
4. Can rigorous and controlled psychological experiments on spatial perception and cognition done in the laboratory be replicated at environmental or geographic scales?
5. Are spatial scale classes created by characteristic scales, activities, and resolutions of human perceptual and cognitive processes and abilities?
6. Can one do an experiment that compares the performance of the same group of participants in spaces of two different scales (or with representations at two different scales)?
7. How are geographic processes at different scales similar and different?
8. How does the situational or task context in scale research influence behavioral data, independent of scale?
9. How does spatial/temporal scale operate as a function of the situational or task context of a study?
10. What, if any, empirical evidence supports a particular classification of cognitive scale classes?
11. Does any evidence support the notion of cognitive scale classes as opposed to a cognitive scale continuum?
12. If there are cognitive scale classes, how can we determine where the boundaries that define classes are located?
13. What is the role of motion in the creation of spatial knowledge at different scales of space?
14. How does the resolution of maps relate to the resolution of spatial representations built up from maps?
15. What are the similarities/differences among the formal structures of scale changes in vision, spatial knowledge, and linguistic knowledge?
16. How do limitations of human cognitive processing interact with scales of spatial phenomena to affect the comprehension and use of information?
17. Does an understanding of scale depend on the medium (is it the same in VR, maps, real space, etc.)?
18. How are spatial and temporal scales similar/different?

19. What happens to scale when dimensionality changes?
20. What would a formal language for expressing/reasoning about 'inter-scale' issues look like?
21. What would a formal ontology/taxonomy of scale concepts look like?
22. Which issues in spatial analysis and aggregation are scale independent and which are scale dependent?
23. How can we achieve continuous scale map generalization ('picto-digital' map generalization)?
24. What is the role of scale and the nature of emergent geographical structures in virtual environments?
25. Can the injection of functional representations of scale alter the viewer's appreciation or understanding of a cartographic display? For example, functionally robust representations of scale might include circles showing:
    -a convenient one day driving distance
    -a one hour walking distance (at 15-minute miles)
    -a $3 taxi ride
26. How does the brain process and combine information at many scales to extract information or patterns? Is this difficult for the brain to do?
27. What is the best method of representing scale changes, such as when a cartographic interface zooms in or out?
28. Do we use natural language differently in describing routes or spaces of different scales, and if so, how?
29. What is the developmental progression of understanding and using spatial language about space of different scales/ sizes?
30. How do we perceive changes in visual scale (e.g. between an aerial view of a city and a perfect scale model)?
31. Are there alignment effects in haptic perception (both objects and configurations of objects)?
32. Is expert knowledge the same across the levels of a classification of cognitive scales?
33. Are there differences between pictorial objects and gigantic spaces transformed into pictorial objects?
34. Is there a distinct advantage to a zoom-in/zoom-out landscape display that provides a continuous transition of scale, in contrast to a discrete display, such as the 9-step vertical height indication used at the Geosystems web site?
35. What are the geometric aspects of allocentric and egocentric orientation - does geometry matter?
36. Does geometry create or conflict with scale (e.g., spherical/planar, Euclidean/non-Euclidean, boundary effects for bounded geometries)?
37. Does affect influence local/regional/global orientation - how does a scale experiment change when subjects become emotionally engaged in task?
38. Can we devise computational models of scale change that preserve: visual logic - geometry and topology; cartographic logic - visual hierarchy; geographic logic - geographic processes?
39. How can scale be manipulated, while controlling other factors, without simply testing size?
40. Are there generic cognitive processes rather than those specifically spatial (e.g., within working memory) that are different for different scales?
41. Do settings of varying extents require different measures of spatial scale understanding (comprehension and representation), how would we determine these, and why would we

want to have such measures?

42. What are the critical covariates to understanding spatial scale in cognition and behavior?
43. How can we conceptualize the relationship between task-specific scale and use of scale at different levels of consciousness?
44. What are the relationships between size of area and detail?
45. How is it best to measure and control scale effects?
46. What cognitive processes reside in the 'gaps' between scale classes?
47. In what ways do our methods create scale?
48. How does scale partition/segment space?
49. What kinds of stories or narratives direct our own understanding of scale?
50. What are the situations in which animated displays are superior to static displays?
51. What is the evidence for or against alignment effects in real environments larger than table-top or room space?
52. What are the relevant reference frames to consider in examining scale in cognition?
53. How does action (e.g. locomotion, grasping, etc.) influence the mental representation of spatial information?
54. How do various action systems differ with scale of space?
55. How does orientation specificity and alignment develop in children?
56. How does children's understanding of scale relations develop over time?
57. How do children construct the world and develop a sense of place through maps and other mediated representations?
58. How does hierarchy operate in spatial cognition?
59. Are there cultural/regional differences in scale classes?
60. Are perceptions of scale changed by motivation, and if so, how?
61. Is understanding of scale changes continuous or discrete?
62. Do different coordinate systems operate at different scales?

V. Participants Who Attended the Workshop.

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VII. Figures

A. Representation theory (Freksa Paper).

B. Fuzzy logic for qualitative size (Freksa Paper).

C. Relative scales for qualitative object size (Freksa Paper).

D. Research paths for studying orientation-specificity (McNamara Paper).

E. Research results demonstrating orientation-specificity (McNamara Paper).

F. Maps by geographers and by psychologists (Breakout Session #3, Group 1).

G. Spatial knowledge as modeled by geographers and by psychologists, Version 1 (Breakout Session #3, Group 1).

H. Spatial knowledge as modeled by geographers and by psychologists, Version 2 (Breakout Session #3, Group 1).

I. The road goes through the park, Version 1 (Breakout Session #3, Group 2).

J. The road goes through the park, Version 2 (Breakout Session #3, Group 2).

Summary Report

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Project Varenius Workshop
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