Title

Cognitive Models of Dynamic Geographic Phenomena and Their Representations, Final Report

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Varenius Workshop Report

Cognitive Models of Dynamic Geographic Phenomena and Their Representations

Pittsburgh, PA, October 28-31, 1998

Initiative Leaders:

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Introduction

The workshop on "Cognitive Models of Dynamic Geographic Phenomena and Their Representations" was designed to bring together cognitive psychologists, geographers computer scientists, and others to discuss theories and methods for understanding dynamic geographic phenomena or for implementing dynamic representations of geographic events. The workshop was held on the University of Pittsburgh campus on October 28-31, 1998. This report summarizes the activities of the workshop, including the discussion of open research questions and awarding of seed grants to participants.

Acknowledgments

The initiative co-leaders want to thank everyone who assisted in the organization and running of the workshop. The steering committee of Tommy Gärling, Georges Grinstein, Mary Kaiser, Terry Slocum, and Michael Worboys, provided a keen sense of direction and purpose in organizing the workshop with one of the most complex themes in the NCGIA series. The topic was of great interest to the spatial information science community. We would like to thank all who submitted abstracts for participation, both those who we were able to accept and those we had to decline due to limitations on number of possible participants. The assistance of the student reporters, Robert Edsall, Jeffrey Jacobson, Kristin Lovelace, and Julie Bauer Morrison, is greatly appreciated. We extend special thanks to the local organizing committee and in particular, Misook Heo, who was the webmaster for the conference, and Susan Strauss, who was the local registrar. We are also indebted to the support of LaNell Lucius and the staff of the NCGIA in Santa Barbara for their administrative help. Finally, we wish to thank the directors of the Varenius project, David Mark, Max Egenhofer, Eric Sheppard, and Mike Goodchild, for their confidence in our non-NCGIA team to lead an enjoyable and thought provoking workshop.

1. Call for Participation

Cognitive Models Of Dynamic Phenomena And Their Representations
A Varenius Workshop

October 29 - 31, 1998
University of Pittsburgh, Pittsburgh, PA

Initiative Leaders:
Stephen Hirtle, School of Information Sciences, University of Pittsburgh
Alan M. MacEachren, Dept. of Geography, Pennsylvania State University

Steering Committee:
Tommy Gärling, Dept. of Psychology, Goteborg University, Sweden
Georges Grinstein, Institute for Visualization and Perception Research, University of Massachusetts Lowell Mary Kaiser, NASA-Ames Research Center
Terry Slocum, Dept. of Geography, University of Kansas
Michael Worboys, Dept. of Computer Science, Keele University, UK

The ability to manipulate, store, and interpret information about changing environments is a critical skill for human survival, and also is very important for geographic information science. Models of the cognitive aspects of dynamic spatial representations are necessary for understanding temporal and spatial changes in environments, for the manipulation of temporal geographic data, and for navigation through changing environments. Furthermore, the use of representational codes may be dependent on the context of the problem, with different entity types resulting in the adoption of different spatial metaphors for reasoning and understanding. For example, an advancing forest fire may be thought of as a moving entity of changing shape and size, even though there is no real motion or growth, but rather a change in attributes at fixed locations. Other examples of dynamic geographic processes include navigation through changed environments, diffusion of diseases, and much slower processes such as glaciations, or continental drift and plate tectonics.

At a database level, we are concerned with issues such as forming discrete representations of continuous phenomena or continuous representations of discrete phenomena. Cartographically, the emphasis has been on animation, but many methods have been used to show temporal phenomena in static maps. The use of dynamic and manipulable interfaces also must be investigated within the same conceptual framework used for observing dynamic phenomena in the real world.

This initiative takes a dual and parallel look at dynamic phenomena in geographic space itself, and at their representations in dynamic displays of geographic information. If research finds that there are systematic differences in human cognitive responses to various kinds of change and motion in geographic space, then different representations may be appropriate for the different situations. If different kinds of computer displays also trigger different kinds of human memory, reasoning, or decision-making, then the match between cognitive models for the phenomenon being represented and those for the display methods will influence how intuitive and usable the display will be.

The purpose of the workshop is to identify and prioritize a research agenda for the topic. The structure of the meeting will be a combination of plenary sessions to identify and debate major issues and directions, and small-group discussions about more specific topics. Partial or full support for lodging and travel to the meeting may be available to participants.

Participation in the workshop will be limited to 25-35 people, and will be by invitation only. Proposals to participate in the workshop should consist 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).

2. Participants

Initiative Leaders:

- Stephen Hirtle, School of Information Sciences, University of Pittsburgh, U.S.A.
- Alan M. MacEachren, GeoVISTA Center, Department of Geography, Pennsylvania State University, U.S.A.

Steering Committee:

- Tommy Gärling, Dept. of Psychology, Goteborg University, Sweden
- Georges Grinstein, Institute for Visualization and Perception Research, University of Massachusetts Lowell, U.S.A.
- Mary Kaiser, NASA-Ames Research Center, U.S.A.
- Terry Slocum, Dept. of Geography, University of Kansas, U.S.A.
- Michael Worboys, Dept. of Computer Science, Keele University, UK.

Participants:

- William Albert, Nissan Cambridge Basic Research, Cambridge, MA, U.S.A.
- Gennady Andrienko, GMD - German National Research Center for Information Technology, Schloss Birlinghoven, Germany.
- Marc Armstrong, Department of Geography, University of Iowa, U.S.A.
- Connie Blok, International Institute for Aerospace Survey and Earth Sciences (ITC), The Netherlands.
- Mary Czerwinski, Microsoft Research, U.S.A.
- Rudy Darken, Department of Computer Science, Naval Postgraduate School, U.S.A.
- Max J. Egenhofer, Department of Spatial Information Science and Engineering, University of Maine, U.S.A.
- Carola Eschenbach, FB Informatik, AB WSV und GrK Kognitionswissenschaft, Universitaet Hamburg, Germany.
- Christopher Habel, Cognitive Science, University of Hamburg, Germany.
- Bin Jiang, Centre for Advanced Spatial Analysis, University College London, UK.
- David M. Mark, Department of Geography, State University of New York at Buffalo, U.S.A.

- Paul Munro, Department of Information Science and Telecommunications, University of Pittsburgh, U.S.A.
- Donna Peuquet, Department of Geography, The Pennsylvania State University, U.S.A.
- Andrea Polli, Academic Computing, Columbia College, U.S.A.
- Juval Portugali, Department of Geography and the Human Environment, Tel Aviv University, Israel.
- John Stell, Computer Science, Keele University, UK.
- Holly A. Taylor, Department of Psychology, Tufts University, U.S.A.
- Barbara Tversky, Department of Psychology, Stanford University, U.S.A.
- David H. Uttal, Department of Psychology, Northwestern University, U.S.A.
- May Yuan, The Department of Geography, The University of Oklahoma, U.S.A.

Students:

- Robert Edsall, Dept. of Geography, Pennsylvania State University, U.S.A.
- Misook Heo, Department of Information Science and Telecommunications, University of Pittsburgh, U.S.A.
- Jeffrey Jacobson, Department of Information Science and Telecommunications, University of Pittsburgh, U.S.A.
- Kristin Lovelace, Department of Geography, University of California at Santa Barbara, U.S.A.
- Julie Bauer Morrison, Department of Psychology, Stanford University, U.S.A.

3. Meeting Schedule

Wednesday

7-9pm: Reception

Thursday

9:00-9:45: Opening Remarks
- Dean Toni Carbo, School of Information Sciences
- Max Egenhofer
- Stephen Hirtle
- Alan MacEachren

9:45-10:30 Visual Representations 1:
- Rudy Darken
- Gennady Andrienko

11:00-12:30 Formal Representations
- Michael Worboys
- May Yuan
- John Stell

2:00-3:30 Discussion Session

4:00-5:30 Cognitive Issues 1:
- Donna Peuquet
- Mary Czerwinski
- Carola Eschenbach
- David Uttal

Friday

9:00 -10:30 Breakout Session 1

11:00 -12:30 Report of Breakout Session 1

2:00 - 3:30 Visual Representations 2:
- Marc Armstrong
- Connie Blok
- Bin Jiang
- Andrea Polli

4:00 - 5:30 Cognitive Issues 2:
- Tommy Gärling
- Juval Portugali
- Barbara Tversky
- Christopher Habel

Saturday

9:00 -10:30 Breakouts Session 2

11:00 -12:30 Reports of Breakout Session 2

2:00 - 3:00 Development of Research Agenda

3:00 - 4:00 Concluding Session

4. Research Themes – Initial Discussion

On Thursday afternoon, after presentations on aspects of visual representations by Rudy Darken and Gennady Andrienko and on aspects of formal representations by Michael Worboys, May Yuan, and John Stell, the first open discussion started. The discussion focused on identifying the critical issues for research on dynamic representations that needed further elaboration and development over the two days of discussion. This brainstorming session resulted in a long list of issues, that were subsequently grouped into the four major categories listed (working categories that have recognized overlap):

Scale and levels of detail

- Sampling of dynamic spatial phenomena
  - How does what we sample effect what we see?
  - What should be sampled, where, how often?
  - How are samples interrelated?
  - How conditional are samples on each other?
  - Do different spatiotemporal processes require different sampling schemes?
  - How does sampling relate to interpolation (and exterpolation) in space and time?
- Data about dynamic system vs. dynamic data presentation
- What are the implications for modeling of sampling in space and time?
- How does the relative level of detail in time and space influence understanding of process? Real time vs. 'Film' time (summaries) (e.g. imagine those Warhol films with someone sitting for 20 minutes).

Taxonomy of events and processes

- Taxomony and partonomy (segmentation) of (spatial and temporal) <u>events</u> and their relationships to each other
- Is there anything about spatial events that nonspatial events do not share?
- Events vs. processes; when is a phenomenon categorized as each?
  - How do we see/treat slow vs. fast? (dichotomy? or continuum?)
  - What are the scale issues?
  - Does the nature of phenomena/data matter (continuous vs. discrete; human vs. nonhuman; individual vs. group, etc.)?
  - Are the above "attributes" of events/processes?
- How should time be represented in databases and visually?

Realism and abstractness

- Process has implications for forms of representation
- Alternative notational representations are needed for dynamic spatial phenomena; notations and presentations for space-time information. Presentation and exploration of data may require alternative notations
- What does realism mean and how much of it do we need?
- How like/unlike 'real' time?
- What is the relationship of realism and abstraction/symbolism (are they ends of a continuum?); How should we schematize/abstract/characterize?
- If we take realism to mean fidelity to environment, is iconic representation better in some ways than realistic representation?
- What are the developmental aspects of realism taxonomies?
- What 'reality' (e.g. in virtual environments (VE)) etc. Is good, good enough?
- Augmented reality; 'super' reality; combination of dynamic processes/displays and 'reality'; to what extent immersive? What different conclusions do we find? What are the different cognitive processes that are invoked for different types of VEs.
- Photorealism; looks same but not act the same at all (e.g. Darken's work on VEs)

Human-computer interface

- Mapping information to users needs and understanding
- Using knowledge to select representation
- Temporal landmarks; saliency of events, pieces of importance, more useful because schematized
- Temporal perception building on a long tradition in psychology
- User control of time (like film editing process?)
- How is time represented in memory? Are space and time encoded independently or together? Evidence suggests that brain regions are separate; short term memory more tied to time; they are processed together.
- Synchronization (broader temporal context) and temporal pattern detection

5. Research Theme Breakout Sessions – Day 2

The first day ended with presentations on cognitive issues to consider by Donna Peuquet, Mary Czerwinski, Carola Eschenbach, and David Uttal. The second day began with the participants being divided into four discussion groups. The groups, derived from day 1 topics, were:

A. *Scale and levels of detail*
B. *Taxonomy of events and processes*
C. *Realism and abstractness*
D. *Human-computer interface*

The researchable themes and specific research problems that emerged from these discussions are identified below:

A. Scale and levels of detail

This group broadened their charge to focus on the way we model space-time phenomena and processes (for database and visual representation) as it relates to how people understand these processes. In addition to scale and levels of detail, the related issues considered in the group discussion included representation form (raster versus vector, visual versus verbal), resolution in time and space, continuity of phenomena and representations (or lack of it), and the interplay between space and time in the construction of phenomena and events. The discussion resulted in lists of specific research questions directed to human understanding of geographic scale events, ways in which dynamic phenomena can/should be represented, and ways to address space-time cognition and representation issues experimentally. The specific issues related to sampling noted on day one were not considered further here.

1) Process detection and reconstruction
   a) Is it useful to fix space, as in a raster model, when studying processes?
   b) How can we create a controlled space-time process?
   c) Can individuals detect/reconstruct process when different temporal scales are used?
   d) Can individuals reconstruct processes better using spatially and/or temporally discrete vs. continuous representations?
2) Key frame caricature
   a) Do people use key points to reconstruct landmarks in space-time?
   b) What things should be retained as key points in a cartographic representation (e.g. Keys of Florida, Cape Cod)?
3) Influences/interplay
   a) How do space and time interact in construction of events?
   b) How does something in time shape spatial knowledge?
4) Verbal reconstruction – possible experimental tasks/questions:
   a) Show space-time process to people, ask them to reconstruct the events

   b) Vary speed, level of discretization
   c) What varies or is consistent across conditions?
   d) Do expectations effect what is seen in significant ways?
5) Inertia – If subjects are shown a sequence of images and asked “what was last frame,” the evidence suggests that they extrapolate and answer what they think is next in the sequence, not what was last.
   a) How does “inertia” apply to non-mechanical worlds/topics?
   b) Will inertia exist for geographic scale processes representing both human and environmental phenomena?

B. Taxonomy of events and processes

This group directed attention to the temporal component of space-time (as the key issue that makes study of dynamic geographic phenomena fundamentally different from past work on geospatial cognition and representation). Emphasis was on events, specifically how to identify them. Specific attention was directed to categories of motion and the role of motion in space-time events. Process was considered primarily in contrast to, or as a conjunction of, events. This group also addressed some issues related to scale. No attempt was made here to link the proposed taxonomy of real world events and processes to similar digital or visual representation taxonomies. The full group discussion, however, raised this problem as an obvious outgrowth of the research issues that were raised. The linking of phenomena and representation taxonomies is clearly critical if geographic information technologies are to be developed to support scientific research, science education, or decision making (more effectively than today’s GIS tools with their static conceptualization of the world).

1) There are four goals of building taxonomies of events and processes:
   a) Account for human understanding
   b) Language for describing models of events
      i) formal models of space/time
      ii) query language for dynamic knowledge
   c) Software to identify and represent events
      i) visualizations
      ii) computational methods to “find” events in large databases
   d) Simulate events/processes to predict and understand

2) What is an event? The following issues were edentified:
   a) Event taxonomies: kinds, attributes
   b) Event partonomies: how are events segmented?
   c) Relations between events
   d) Scale issues: resolution
   e) Event model: Object model vs. Category events (how much carry over?)
   f) Are geographical events (market, geo-political entity, city) comparable to other temporal events (e.g., turn of the century)?

3) Survey of philosophical analyses of events
   a) Motion is a key to events: continuous/discontinuous, trajectory
   b) How do we conceive of motion, and how does it actually occur?
   c) Field vs. object: fire, disease may be physically different but conceptually similar

4) Motion:
   a) as a cue to "objectness"
   b) as a device in visualization

5) Several more dichotomies were noted:
   a) Slow/fast
   b) Continuous/discrete
   c) Human/nonhuman root of event taxonomy
   d) Individual/group

C. Abstraction and realism

The primary issue for this group was the interaction between concrete visual representations of space-time phenomena and processes (e.g., animations) and mental representations of those same phenomena and processes. How to design effective visual representations and how to study the interaction between these representations and mental representations were both addressed. An overarching issue was the relative advantages and implications of realism versus abstraction for different use contexts and different categories of user. Emphasis in most of the discussion was on representation of visible aspects of the world (thus on tasks such as navigating through the environment, tracking moving objects, etc.). Most of the specific research problems and methods for studying them represent this emphasis. Missing from the discussion was the equally important question (raised in the full group session) of how space-time phenomena and processes that are not visible in the world can be most effectively represented visually and how human understanding of movement and change for visible phenomena influences conceptualization of non-visible phenomena.

Motivation for the Research -- What is the association between physical representations (abstract to real) and mental representations?

1) When are iconic physical representations useful?
   a) What are the advantages and disadvantages of realism?
   b) Under what conditions?
      i) For what age groups?
      ii) For what cultures?
      iii) For what experience levels?
      iv) With what level of detail used in instructions?
2) What is the allowable level of abstraction?
   a) What is the minimal landmark set?
   b) What symbols should be used?

   c) How salient do landmarks need to be?
      i) how to determine them
      ii) when/where to use, etc.
   d) What user expectations exist for symbol meaning?
   e) How do we train users; does training transfer?

3) Are there fundamental principles about physical representations (p-reps) that afford useful mental representations (m-reps)?
   a) What characteristics of the user do we need to study to know this? (Age, gender, culture, experience, expertise, goals, task, etc.)
   b) Transfer studies:
      i) Test same physical representation in different environments
      ii) Test same environments using different physical representations
   c) How do we support error recovery in the physical representations?
      i) Is this a recognition memory question (task)?
      ii) What user strategies succeed and how do we design or train for them?
   d) How do emotional/personality traits affect all of these research questions?
   e) How does the interaction style influence mapping of p-rep's to m-reps? (input, display)?

4) Dynamism and Type of Task
   a) How does p-rep/m-rep mapping change if the environment (but not the user) is moving?
   b) Targeted search vs. exploratory browsing--do they require the same p-rep?
      i) What if a target changes on the fly?
      ii) What target visibility/predictability issues exist and how can they be addressed?
   c) For moving environments or users, what conditions lead to acquisition of pure route versus survey knowledge (or an intermediate form)?

D. Human Computer Interface

The emphasis of this group was, primarily, on how to represent dynamic geographic phenomena to users (thus on visual representation) and on methods for allowing users to interact with these representations. With the former, topics considered include the role of abstraction in understanding of dynamic phenomena, notational systems for dynamic phenomena, depiction of covariation between or among changing phenomena, and issues of space-time scale. With the later, the focus was on notation for interaction and collaboration (among humans) about, and facilitated by, dynamic representations. Also considered were issues related to perceptual/cognitive errors in interpretation of dynamic displays and the relation of different representation forms (e.g., multiple static images versus animation) to these errors. A distinction is made between dynamic representations and representations of dynamic phenomena, however, the specific interface issues associated with each were not developed further. Specific research questions identified include:

1) Can we identify/provide domain-specific *notation methods* and *models* in a system for representing dynamic phenomena, or should we attempt to generalize notational methods across domains? Can/should we provide a manipulable/dynamic/interactive notational system?

2) Does the (cartographic) abstraction process enhance understanding of dynamic phenomena in a representation? Should we strive for fidelity/realism?

3) How can we best represent covariation among changing variables in dynamic displays? Can we represent such statistics in purely graphical/visual/perceptual displays or do we need numerical references? Do we need *dynamic* displays for these representations?

4) How do we provide users with access to different/alternative representations of "levels" and scales of space and time… how can the levels overlap and be linked in a representation?

5) Can there be effective *collaborative* interactions (among humans) with a dynamic representation? In real time? Do we need to make distinctions between *dynamic representations* and representations (which could be static) of *dynamic phenomena*?

6) Are there generalizable (temporal) *errors* in perception of dynamic displays? What is the role of temporal lags in perception across multiple dynamic representations? Are there ways of guiding (visual) attention through a dynamic display to reduce error? Do dynamic displays allow more cartographic "slop" (or does it correct for sloppy cartography, "wrong" color schemes/classifications, by allowing a user to gain multiple perspectives instantly)?

8. Breakout Session 2 – Delineating a Research Agenda

Friday afternoon continued with two additional state-of-the-art presentation sessions. These were on visual representations with presentations by Marc Armstrong, Connie Blok, Bin Jiang, and Andrea Polli and on cognitive issues with presentations by Tommy Gärling, Juval Portugali, Barbara Tversky, and Christopher Habel. The participants divided into four groups on Saturday morning to continue discussion of open research issues and to formulate a more specific research agenda. The topics and attendees at each group were:

> *A: Cognitive research issues associated with perception and cognition of real world dynamic geographic phenomena and how to model our mental/cognitive representations of those phenomena* -- David Uttal, Juval Portugali, Bin Jiang, Tommy Gärling, Carola Eschenbach, John Stell, and Kristin Lovelace
>
> *B: Cognitive research issues associated with use of animated representations and virtual environments directed to dynamic geographic phenomena* -- William Albert, Rudy Darken, Connie Block, Christopher Habel, Barbara Tversky, and Jeff Jacobsen
>
> *C: Cognitive research issues associated with various new forms of interaction with geographic information access and display environments* -- Terry Slocum, Gennady Andrienko, Andrea Polli, Max Egenhofer, Holly Taylor, and Rob Edsall.
>
> *D: What do we expect/hope that geographic information analysis environments a decade from now will/should be able to do to allow us to show related dynamic geographic phenomena* -- Michael Worboys, Donna Peuquet, David Mark, May Yuan, Marc Armstrong, and Julie Morrison

The researchable areas and critical issues, that emerged from these discussions, are outlined below:

A. Perception and cognition of real world dynamic geographic phenomena and how to model our mental/cognitive representations of those phenomena

This group examined the general problem of perception and cognition as these systems relate to human understanding of dynamic geographic phenomena. The problem, of course, is that perceptual processes in reasoning are difficult to quantify and therefore difficult to imbed in dynamic systems. There is an inherent tension in building systems, between presenting information that in some sense is truthful and accurate and presenting selective information that highlights important characteristics of the data. In addition, the group discussed the role of expertise in understanding dynamic phenomena. Specific research questions develop by this group include:

1) How do people understand real-world dynamic geographic phenomena (e.g., how are the understanding of space and time integrated)?
2) Does perception equal cognition?
   - Consider expert vs. naive models in various domains, such as sports, meteorology, etc.

- What are cognitive and perceptual variables that are critical to attend to (e.g. 3D display often lead to attentional problems)?
- What are differences among cognition and perception of the real world and of displays?

3) How does one perceive causality at a geographic scale? Is there a difference between perceived and inferred causality?
4) Is causal thinking an innate or cultural phenomena? Since causal thinking is often misapplied and users tend to over-casualize, how can we work against those tendencies in displaying information?
5) Do we want to build on what we already know about cognitive processes or try to get around them? Examples: heuristics, 'interpreter' in brain, social attribution
6) To generate *meaningful* displays, we want patterns for users to see. User and computer should be engaged in an iterative process, each with strengths (e.g. humans are better visual pattern recognizers, which computers can't match; computers are better at finding patterns in other kinds of data (verbal, numerical, satellite pictures, etc.). Augmented reality provides an example of merging the strengths of human perception/cognition and computer processing.
7) How to model cognitive representations? Issues identified include:
   - Models of cognition and perception take a variety of forms: verbal vs. mathematical, self organizing, neural net, situated cognition, behaviorist, production system, evolutionary, etc.
   - Consider the range of types of phenomena being modeled: meteorological, city design/dynamics, navigation, migration, traffic flow (auto or pedestrian)
   - Consider development of hybrid models.
   - Meta-theoretical issues: a) will coming up with a good science model lead to a good system for visualization, b) is there a separation of perception and cognition (e.g. visual processing vs. causation inference), c) that is the 'real world'? Separation of representation and reality, d) what are the spatial dynamic tasks that someone might do and how are they related to the models and representations?
   - Effect of expertise is an important researchable issue. It can help give us a handle on how people think about dynamic phenomena. Some examples of domains in which experience with understanding spatiotemporal phenomena matters include: sports, meteorology, fishing, farming, forestry. One question here is what correlation exists between age and expertise?
8) How relevant are results on small-scale (tabletop or room size) dynamic phenomena to our understanding of large-scale phenomena? Do the results 'scale up' in time? Consider space and complexity examples, such as the naive physics of tornadoes or earthquakes or how to explain or predict growth of cities.

B. Cognitive research issues associated with use of animated representations and virtual environments directed to dynamic geographic phenomena

The purpose of this group was to discuss research issues related to cognitive representations of dynamic geographic phenomena as they may be influenced by animated and dynamic external representations (e.g., interactive “map movies” or dynamic virtual worlds). Many specific issues were discussed, but three general themes emerged. First, some issues dealt with how dynamic geographic phenomena are externally represented in an animated or VR environment. Of particular interest is the mechanism by which different types of external representations interplay with our internal cognitive representations. A second theme to emerge focused on human comprehension/understanding of dynamic geographic phenomena. Specifically, different factors were discussed which either inhibit or facilitate understanding of dynamic geographic phenomena in an animated or VR environment. Third, research issues were discussed related to process, or how we make a direct mapping between what we experience in a VR environment and our actual movement in space. That is, what are the factors that influence the ease or difficulty in making a translation between what we experience in a VR or computer animation and our behavior or decision-making?

Specific research questions develop by this group include:

1) How can we use (display) space and time to represent dynamic geographic phenomena?
2) How do people comprehend or understand the use of animation and virtual environments; what is the interplay of cognitive representations of reality and these display types?
3) How do we schematize information from virtual environments or animation?
4) Consider the difficulty of understanding three dimensional representations
   - Can we combine 3d and animation to overcome the difficulty of each representation alone?
   - Are there effective ways to build 3d representations through 2d slices?
5) What can time effectively represent besides temporal data? Would it include any ordered information?
6) When is it useful to consider a non-linear time scale?
7) How do we comprehend and understand animation and virtual environments?
8) When does teleporting result in conceptual confusions? Are there conditions when it does not?
9) Is there a conceptual difference between dynamic representations of phenomena we can experience and those we cannot? What are the design implications based on how we may represent these different kinds of phenomena?
10) Animation seems best or easiest when there is a natural mapping, i.e. animation represents an actual motion. However, the most interesting phenomena are the more difficult: when non-temporal events are animated.
11) How can we develop effective ways of manipulating the space-time continuum in VR?
12) Can schematized “things” be used to save cycles in VR?
13) When is it better to use a VR to get inside things, rather than look at them from the outside?

C. Cognitive research issues associated with various new forms of interaction with geographic information access and display environments;

This group focused on new forms of display environment and human-computer interaction with (and within) these environments as it relates to depicting and understanding dynamic geographic phenomena. A general conclusion arrived at by the group is that, if we expect to produce geoinformation technologies that help people understand complex and dynamic geographic phenomena, it is necessary to incorporate new methods of interaction, including: voice, eye movement/fixation, sketching/gesturing, and collaborative/multiple-user interactions. Taking advantage of new wrinkles in traditional methods, such as developing information-rich active legends, also has the potential to produce more effective human-computer interaction. In relation to these new environments and forms of interaction, several specific research issues emerged:

1) What are the bounds of abstractness in space-time representations for maximum information retrieval? Can we have too much information in a dynamic display? How much is too much information and why? How fast/how detailed does a display have to get before it becomes overwhelming? How do we control the level of abstractness?
2) Are geographers constrained by the map metaphor? Are experienced users/analysts of spatiotemporal information *constrained* by their mental models of space-time or does their experience allow them to be *more flexible* in their conceptualizations? What factors influence choice of interaction methods for/with dynamic geographic phenomena? Possibilities suggested include: gender, age, education, expertise, culture, profession, natural language
3) Can we identify the different spatial concepts that the naïve user has vs. those of experts that come from different backgrounds?
4) Why do these factors influence the interactions? Do they prompt different mental model of dynamic geographic phenomena? Can we teach methods used by one culture/level of expertise etc. to another group to gain new insights (to prompt new mental models)?
5) How do we summarize/aggregate dynamic geographic phenomena? Within medium and across media (use of video and text, eg)?
6) Are there differences in methods of interacting with “real” vs. “viewable” phenomena? Is there a difference between physical and human phenomenon representations? Diffusion of population as opposed to more “random” events like tornadoes or fire events, etc.
7) How do we conceive of elevation or other “third” dimensions? (location in time, attribute “space”)?
8) How do we structure interactive environments for multiple users? What factors in collaborative use environments should direct our design of interaction methods?
9) How do individuals use data-rich or active legends? Do different (semi-traditional) interaction methods prompt different mental models? Can different mental models, prompted by innovative interaction methods, provide new insight into data or confuse users?
10) How can interaction methods (interfaces) augment reality?

D. What do we expect/hope that geographic information analysis environments a decade from now will/should be able to do to allow us to show related dynamic geographic phenomena?

This group took a look into the future and speculated on potential developments, which have technical limitations today, but will be possible with expected changes in technology over the coming decade. The group considered both changes in hardware, including increases in computing power and the availability of high bandwidth and wireless technologies, and changes in amount of data available for analysis and archiving.

1) What expectations will changes in hardware lead to?
   - Will the capacity to process changing geospatial data become more than adequate or is there never enough technology/capacity?
   - Given the existence of global wireless communication networks, miniaturization, implants, wearable computers, etc., will the location of the user become less important?
   - Interactions of data/process/event, and analysis: data from multiple sources will need to be transformed into events/processes; analysis in the field when/where required.
   - How will users interact with data? Can we adapt to interfaces, which will become portable and natural to augment reality, such as to overlay scenes with information?

2) What are the critical issues to consider?
   - Data explosion, archival, accessibility
   - Source explosion, integration, metadata
   - Higher dimensional effects of artifacts
   - Presentation
     - realism leads to clutter
     - symbolism + augmentation may work best
   - How does/can augmented reality help, in cognitive ways? Can it be a hindrance?
   - Social issues: take account of gender, age, culture, expertise etc. (human factors research is difficult with basic GIS, let alone with dynamic environments)
   - Effect of legal/social/political climate on data accessibility; electronic commerce, privacy vs. right to know with data; issues of liability

3) Examples:
   - Urban planning: visualize political environments (future or past), dynamic construction sequences, represent and simulate dynamic urban environments (movement within them)
   - Weather, climate systems: 4+ dimension spaces, events and processes not just data
   - Transportation systems, intelligent, language of events and processes, goal oriented processes, what sort of interfaces appropriate?

6. Research Agenda – Summary

Dynamic geographic phenomena exist at multiple spatial and temporal scales (and across scales). These phenomena vary dramatically in form. Examples include *flows* (of people, money, information, water, ice, and lava), *events* (such as forest fires, earthquakes, traffic accidents, and military battles), and *processes* (such as global economic restructuring, gentrification of a neighborhood, global warming, and stream sedimentation). The geospatial data needed to study these issues are being generated from a wide range of sources (including satellite sensors, GPS, the census, and e-commerce activities). Our geospatial information technologies, however, are not up to the task of taking advantage of the exponential increase in data that is occurring. GIS and related technologies are not designed to represent and facilitate analysis of phenomena that change and move.

A focused effort is needed to address this problem on two fronts. First, we need new approaches to database representation and data access that supports dynamic phenomena and the questions science and society want to ask about these phenomena. Second, to build geoinformation technology that works, we must develop human-centered systems that take into account, directly, human understanding of dynamic geographic-scale phenomena and their representation. It is the later issue that was the focus of this workshop and to which the research agenda detailed here is addressed.

Based on both initial input from participants in the form of position papers (see below) and discussion during the workshop, the following contentions represent group consensus on current knowledge and needed action:

- how humans conceptualize dynamic geographic-scale phenomena is poorly understood;
- the interaction between external representations of dynamic geographic-scale phenomena and human conceptualizations of them is poorly understood;
- to develop geoinformation technologies that facilitate science, learning, and solutions to pressing problems of a dynamic world, we must develop an understanding of both.

This leads, more specifically, to the four broad research objectives identified:

- to understand and model human perception and cognition of dynamic geographic-scale phenomena;
- to understand the interaction between display forms (particularly those provided by new display techologies) and mental representations of these phenomena;
- to understand the interaction between new interface forms and mental representations;
- to anticipate the potential and challenges that will be posed by advances in information technology – thus to think “outside the box” of traditional mapping/GIS practice.

Discussion of these themes resulted in a range of specific research problems to address with several cross-cutting issues. Not surprisingly, the cross-cutting issues relate to the interface between human conceptualization of dynamic geographic phenomena and our representation of them through geoinformation technologies. Three are highlighted here.

First, is the recognition that we are facing an information explosion that requires new approaches to deal with the increasing complexity and temporal frequency of information available and the corresponding complexity of problems being addressed. A promising approach to this problem is to integrate the strengths of human and computer information processing abilities in more sophisticated ways. For example, human experts might guide computational agents in developing a characterization of a dynamic process through which the agent can then search a database for processes that are similar. Similarly, we might develop highly dynamic virtual environments that allow people to experience dynamic phenomena through multiple senses (not relying only on vision) and to interact with these representations in more natural ways – and perhaps with one another in collaborative efforts to understand complex phenomena.

Second, as we merge geoinformation technologies with virtual environment technologies, a set of fundamental questions are raised about the influence of representational realism on human thinking. These questions include perceptual, cognitive, and social issues. At a perceptual level, we need answers to questions such as how detailed a display can be before it becomes overwhelming and whether humans can cope with more or less detail when the display is a visual representation of some aspect of the visible world in contrast to a representation of some non-visible phenomenon or abstract concept. Cognitively, we need answers to questions such as what effect does realistic versus abstract representation of a process have for learning about that process or transferring an understanding of the process in one context to decision making about a related process in a different context. In relation to social implications of geoinformation technology, an understanding is required of the role of realism in public presentation of scientific results or policy decisions about geographic scale events and processes.

Third, to address these and the other more specific questions raised above, a systematic examination of the concept of dynamic geographic phenomena is needed. It is clear from both position papers and discussion during the workshop that participants considered a broad range of phenomena to fit within this label. Some examples include forest fires, traffic accidents, global warming, a person or persons walking through a city, a hurricane, population diffusion, growing and shrinking of the ozone hole, or network traffic on the WWW. To do experimental research about cognition of dynamic geographic phenomena, build cognitive models to represent the mental processes, or design and assess geoinformation technologies intended to facilitate human understanding will require that we first understand the scope of the problem domain. A formal taxonomy of geographic events and processes in needed to support generalization from one context to another.

The goal of this workshop was to raise research questions and it has succeeded in raising a wide range of particularly challenging ones. The multiple disciplinary and theoretical perspectives brought together by workshop participants led to a stimulating three days of discussion and have provided a base from which to progress. We look forward to results of research activities prompted by this effort to engage the topic of cognitive models of dynamic geographic phenomena and their representations.

9. Seed Grants

The final activity of the Workshop was to review and recommend funding of seed grants. Eleven topics for seed grants were proposed at the workshop. Of these ideas, the following four proposals were funded.

"Development of Tele-Immersive Environments for Visualizing Dynamic Geographic Information"

Marc Armstrong and Alan MacEachren

The purpose of the proposed research is to develop new capabilities that are designed to help users understand geographic phenomena through the use of networked, same-time, different-place immersive visualization technologies. The focus of the proposed project is to lay the groundwork for joint research on collaboration in a tele-immersive environment for visualizing dynamic geographic information. This “groundwork” includes the adaptation of technology for immersive visualization and high speed network communication, the outline of a set of fundamental principles of immersion in geographic visualization, and identification of key cognitive research questions that must be addressed if we are to take advantage of the new technologies. Potential capabilities will be demonstrated through a pilot project and a proposal will be prepared for outside funding that is needed to pursue the ideas in greater depth.

"Animation Project Proposal"

Julie Morrison and Barbara Tverksy

In this first set of experiments, we will be investigating the efficacy of animation as it is used to convey the motion of parts of a system relative to one another. In many cases, geographic scientists are interested in depicting real world motion, whether it be navigation through an environment, disease diffusion, or other geographic processes. It is important to know, therefore, whether animation is effective in conveying this type of information, and if so, why. Although research has shown many failures of animation to aid understanding (Lowe, in press; Gurka & Citrin, 1996), animations that convey *motion* information have been shown to be successful (Baek & Layne, 1988; Hays, 1996; Rieber, 1990).

In this second set of experiments, we will be investigating the efficacy of animation as it is used to convey change in distribution of data. One problem with using animation to present distribution of data occurs when people infer a causal relationship that does not exist. Another related problem is that people may not notice real causal relationships among variables. We are interested in investigating the circumstances under which people correctly and incorrectly identify relationships in data.

This proposed research will serve as only the beginning in a long series of investigations into the efficacy of animation. The above sets of experiments are the starting point of this research and should lead to a greater understanding of the role of animation in conveying both motion information and distribution of data information. Further, secondary studies should allow us insight into the more detailed issues surrounding the use of animated displays. If the future of geographic science is to include successful dynamic representations of geographic information, we first must be able to identify what information is to be conveyed then empirically develop the appropriate methods with which to convey that information.

"A Preliminary Evaluation of MapTime"

Terry Slocum

Under the direction of Terry Slocum, Stephen Yoder, has developed a software package, entitled MapTime, to assist users in exploring a wide variety of spatio-temporal phenomena associated with point locations (Yoder, 1996). Although MapTime provides a wide range of methods for exploring spatio-temporal phenomena, it has never been evaluated by potential users. One purpose of this proposal is to begin such an evaluation. An important element of this evaluation will be an examination of the cognitive models people have of spatio-temporal phenomena associated with point locations and a corresponding consideration of how these phenomena should be depicted (symbolized) within data exploration software such as MapTime.

"Acquisition of Spatial Knowledge as a Dynamic Phenomenon"

Holly Taylor and David Uttal

A central theme at the recent Varenius Workshop, Cognitive Models of Dynamic Geographic Phenomena and Their Representations, was that the processes of acquiring and using spatial information are dynamic in several senses. First, spatial representations must be updated to comply with available perceptual and conceptual information. Through updating, information may be added, deleted, or altered in ones current mental representation. Second, successful use of a spatial representation often requires shifting from one representational format to another. For example, an environment can be represented in one of two possible spatial perspectives, either route or survey, but information from the other perspective may be needed when traversing or describing the environment. The work proposed will contribute to our understanding of how people flexibly represent the environments in which they navigate and how the relevant abilities develop. The proposed work would facilitate a new collaboration between researchers who bring different perspectives (cognitive and developmental) to these issues.

10. Participant Papers

This section includes the initial position papers submitted by those selected to participate in the workshop. They represent a wide range of topics relevant to the theme of the workshop and provide an important context from which to interpret the research agenda developed during the workshop. Several of the specific research questions raised during the workshop are discussed in greater detail in these papers and, in many cases, the position papers contain citations that should be a useful starting point for those who decide to accept the challenge posed by the research agenda delineated here. Position papers appear in alphabetical order by participant's surname.

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Exploring the Representation of Time and Space During Route Learning
in a Virtual Environment: A Preliminary Study.

Introduction

There have been many studies, which have explored how humans learn and maintain *spatial* representations of the world around them (Piaget & Inhelder, 1967; Hart & Moore, 1973; Siegel & White, 1975; Golledge, 1998). As in many other areas of cognition, however, the *temporal* dimension of our experience with the world has been largely ignored. This is not to say that time is never considered, as there are clearly paradigms in which the experience of time is of central interest (e.g., time-to-collision, Lee, 1976). However, in studies of how we acquire knowledge of specific environments or routes, space rather than time has been the dimension of choice.

At Cambridge Basic Research (CBR), an important thrust of our research has been to extend the traditional human factors perspective on driving by using the concept of "mental models". While mental models are somewhat hard to define, there is a general agreement that they must go beyond traditional concepts of representation in capturing aspects of *function* and *use* as well as simply declarative knowledge of a domain. An important aspect of this difference is the idea of representing dynamics. As Moray (1990), has pointed out

> "..When a person has performed a task...for a long period... he or she acquires a mental model of the dynamics in *space* and *time* of the variables relevant to the task..." (emphasis added).

The focus on mental models is extended by asking how a drivers experience with an environment, both in space and time, influences their internal representation of that environment. While a number of researchers have argued for a more general consideration of both space and time in mental representation (Jones, 1976; Shepard, 1984; Freyd, 1987), this may be the first study to explicitly probe for "dynamic mental representations" (Freyd, 1987) within the context of driving.

General Method

During an initial learning phase participants are shown a computer simulation of a drive through a simple route. The route currently consists of 9 road segments of variable length, which are connected by a series of 90° turns, (4 left, 4 right). Nine landmarks are placed at variable intervals along this route. The landmarks consist of simple "block" buildings and geometric structures (e.g. a tall Washington Memorial-like obelisk).

Where the current paradigm differs from most route learning studies is in altering the velocity with which the car is driven during different portions of the route. As time-distance relationships are dependent upon velocity, this manipulation allows us to probe both sensitivity to velocity change, but more importantly, the impact that such changes have on internal representations of the environment.

Participants are told to pay attention to all aspects of their journey through the route as their memory for this journey will be tested at a later date. Participants are warned that their velocity may change and that they should try to be aware of such manipulations. Four basic measures are used to assess the mental representations, which evolve during this route learning task:

Spatial knowledge is assessed via 1) map drawing and 2) placement of landmarks on an abstract distance scale. Subjects assume that the total length of the route is 100 units. They must locate each of the nine landmarks along this 100-unit scale.

Temporal knowledge is assessed via 3) placement of landmarks on an abstract time scale (assuming the total time of the route is 100 units long), and 4) a "mental navigation" task in which we measure the time taken to "imagine" driving either the whole route or sections of the route. As well as basic time production, an interruption method is also used where a verbal stop signal is used to probe how far a long the route a participant has "mentally driven" during a certain time frame.

Research Goals

1) Develop a paradigm to probe the development and maintenance of temporal as well as spatial knowledge during route learning and navigation tasks. Methodology for probing spatial route learning is already well established (see Kitchin, 1996, for a comprehensive review). I extend this methodology by explicitly probing for temporal information and introduce a "mental navigation" task which has it roots in the mental rotation work of Shepard and his colleagues (e.g. Shepard and Meztler, 1971) and the mental imagery work of Kosslyn and his colleagues (e.g. Kosslyn, 1995).

2) Study the relationship spatial and temporal knowledge in a driving context. This will be achieved by first, measuring the accuracy of distance and time estimations between landmarks, followed by determining if there are any systematic distortions in the distance and time estimations. Secondly, performance will be analyzed on landmarks within the same speed segments and across different speed segments. This analysis will shed light on how well subjects are able to take into account velocity changes in their estimation of distance and time between landmarks. Finally, the mental navigation task will offer insight into the accuracy and detail of their dynamic mental representation of driving.

Overall, I hope to gain a better understanding how drivers develop cognitive models of their environment which include both *space* and *time*. This research focus is particularly important since drivers may often select routes based on travel time, rather than distance. There also may be important implications for the design of in-vehicle navigation systems since drivers may be presented both spatial and temporal information about routes.

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1. Overview of the Descartes system

Our system Descartes (see Internet variant at http://allanon.gmd.de/and/java/iris/) is intended to help users to comprehensively analyze various spatially referenced attribute data. To meet these objectives, we develop in the system the following capabilities:

Automated knowledge-based generation of maps that correctly (i.e. in compliance with the principles of graphical and cartographic design) represent user-selected data variables.

Automated generation of non-cartographic data displays (dot plots, scatter plots, box-and-whiskers plots) supplementing the maps. All displays, cartographic and non-cartographic, produced by the systems are *linked* with each other.

Interactive facilities to manipulate the map displays that dynamically change their appearance in response to user's actions. These dynamic techniques are designed so as to promote revealing interesting patterns in data distribution.

Necessary data manipulation functions: database querying, calculations, formation of derived attributes.

It is supposed to enhance the system by developing the ability to intelligently assist the user in the utilization of the offered instruments of data analysis. This will be done on the basis of knowledge about conceptual structure of a database under analysis and the underlying problem domain. This kind of knowledge is already used in Descartes as its consideration is indispensable for adequate map design. So, adding the new capability essentially means developing the potential of the system by extending the usage of knowledge about data.

2. Related research

A pioneering work in automated knowledge-based visualization design was done by J.Mackinlay. His software system APT can encode data variables, according to their types and cardinality, by J.Bertin's ***visual variables*** and construct graphical displays combining these visual variables. This approach was adapted by F.Zhan and B.Buttenfield for selection of an appropriate cartographic presentation method for one spatially referenced data variable. Later V. Jung developed the system Vizard capable of automated mapping of several independent variables. Vizard accounts for not only data characteristics but also user's objectives though the latter are indicated in terms of predefined generic tasks being either rather primitive or rather abstract: lookup, locate, compare, see distribution.

Descartes takes into account data characteristics and conceptual relationships among data variables. For example, the system can "understand" that the database fields with numbers of female population from 0 to 14 years, female population from 15 to 64 years, male population from 0 to 14, and so on, essentially refer to one and the same variable "population number" measured for different age and gender groups, and that these groups are parts of the whole population. This kind of knowledge allows grounded selection of particular presentation techniques such as maps with pie charts or segmented bars. The same knowledge can be effectively used to guide the user in data analysis through communicating with her/him about her/his objectives in domain-specific terms rather than on an abstract level. On this potential we intend to base the further advancement of Descartes.

The use of direct manipulation techniques for visual data exploration was originally proposed in statistics by W. Cleveland. The most widely known is his idea of visual *linking* of several graphical displays by means of *brushing*. M. Monmonier suggested to apply this technique to maps linked with non-cartographic displays. Later the idea of linking between different maps and other graphics was implemented by J. Dykes in his CDV system. CDV also offers facilities for interactive *change of map symbolism*, investigating contiguity relationships, and some others. It's worth saying that interactive tools for changing presentation parameters with the aim of making maps more expressive was proposed by T. Yamahira et al. much earlier than the notion of dynamic displays emerged. These researches developed a histogram interface for selection of intervals for a classed choropleth map. Later S. Egbert and T. Slocum considered interactive classification as an exploratory task.

A well-known group of dynamic manipulation techniques is devoted to database querying: the user is given convenient graphical widgets to alter query conditions and can immediately observe corresponding changes in graphical presentation of search results ("*Dynamic Query*" proposed by B. Shneiderman and S. Ahlberg, "*Attribute Explorer*" and "*Influence Explorer*" by H. Dawkes et al.).

Descartes offers a number of interactive exploratory techniques:

- ***linking*** of maps and other displays;
- ***visual comparison*** with an interactively selected value;

- ***one- dimensional and two-dimensional dynamic classification*** with the possibility to study distribution of values of different variables over classes;
- ***interactive focusing*** on particular ***qualitative*** values or their subsets;
- ***outlier removal*** and ***interactive focusing*** on ***numeric*** value subranges.

Our special interest is in designing dynamic manipulation techniques being inherently connected with map symbolism and enhancing expressive capabilities of presentation methods they address.

In connection with the user guidance we intend to implement the earlier mentioned Vizard system can be referred to. This system not only designs maps but also explains why this or that solution is proposed and which opportunities for analysis it offers. However, the parts concerning analytical opportunities are merely general descriptions of cartographic visualization methods with no regard to user's specific data and goals. Our plan is to guide the user by proposing her/him a number of analysis scenarios specifically allowed by data at hand. Such scenarios are automatically constructed on the basis of system's knowledge about the data and the underlying problem domain, about potential capabilities of different presentation methods, about available dynamic manipulation techniques and other system functions.

3. User guidance: why and how.

Comprehensive data analysis usually requires quite a number of operations with data and their display. Accordingly, the functions and facilities available in Descartes are numerous. This means that the user should learn them and always keep in mind. Further, a rather long sequence of operations is often needed to proceed from source data to a useful presentation. For example, it may be necessary to transform absolute values to percentages, calculate differences or ratios, filter database records, etc. We intend to "wrap" such operation sequences into analysis scripts presented to the user as various analytical tasks formulated in terms of analyzed data and domain notions. These scripts will, first, simplify the acquaintance with the system and release the users from memorizing its capabilities and, second, save time and efforts of even experienced users.

The following example explains our idea. Suppose that a dataset under analysis contains earlier cited fields with absolute population number in gender-age population groups for different countries. The system can foresee several analytical tasks that can be done with the use of these data: "study how gender structure varies depending on age", "study how age structure varies depending on gender", "study gender (or age) structure across countries irrespective of age (or gender)", "examine a particular age group", etc. These or similar formulations are proposed to the user as alternatives to select from. Standing behind each task is a sequence of operations resulting in potentially useful presentation or several presentations and, possibly, some recommendations how to use them and how to proceed further.

Suppose that the user has selected the first "task", study of dependency of gender structure on age. In response the system automatically calculates percentages of male and female in all age groups and creates a map with segmented bars: bars correspond to age division, and segments show proportions of male and female. Note that automation of calculating percentages and selection of this type of presentation really requires knowledge of conceptual relationships among fields.

Displaying the map to the user, the system supplies it with a brief comment explaining that this map is suitable for seeing local differences in gender structure depending on age in each country or for pairwise comparison of countries. It does not help in seeking for spatial patterns and trends. Thus the system offers as a direction for further investigation to take separately male or female percentages and consider their spatial distributions for different ages. Alternatively, the user may be proposed to concentrate on studying differences in percentages of male and female population depending on age. For the first task a series of choropleth maps would be suitable. In the second case the system would automatically calculate the differences and represent them by bar chart map. At the next step the system may propose the user to study spatial distributions of differences for the age groups.

User guidance applies also to the utilization of dynamic manipulation facilities for data analysis. Again, the system can help the user not only by a general description of this or that tool ("static" on-line help) but also with some data- and analysis context-specific recommendations. For instance, if in the course of analysis a ratio of two numeric fields was calculated and presented, the system can propose to apply visual comparison with the value 1; for a difference of two fields visual comparison with 0 is reasonable. In both cases the map will change so that the geographical objects will be visually classified into 3 groups: 1) field1<field2; 2) field1=field2; 3) field1field2. The system can also automatically detect cases when dynamic outlier removal is necessary and propose the user to do this.

It should be noted that the use of guidance is optional: the user does not have to analyze data according to proposed scenarios. S/he always has the possibility to apply any of the available functions in any order. This is important as we cannot guarantee that it is possible to foresee all imaginable analysis tasks. Yet, since the guidance is proposed stepwise the scripts may occur to be useful for partial automation of rather sophisticated investigations.

In guiding the user the system utilizes the following kinds of knowledge:

A) Generic analysis tasks such as "Local comparisons of values of attributes", "Looking at spatial distribution of values of an attribute", "Local consideration of proportions" etc. The tasks may have applicability conditions. For example, the latter task is meaningful for a set of data fields that together constitute a meaningful whole. Unlike the generic tasks in the Vizard system, our tasks are patterns rather than simply abstract statements. The patterns have slots filled with appropriate domain notions when the system proposes analysis scenarios to the user.

B) Knowledge about methods of cartographical and graphical presentation available in the system: which generic analysis tasks are enabled by each of the methods. For example, "Parallel bars" "Local comparisons of values of attributes", "Choropleth map" "Study spatial distribution of values of an attribute", "Scatter plot" "Look for relationships between two attributes". Some presentation methods offer different opportunities depending on data they applied to. For example, "Pie charts"/absolute quantities "Local consideration of proportions", "Comparison of totals"; "Pie charts"/percentages "Local consideration of proportions", "Comparison of proportions for pairs of geographical objects".

C) Knowledge about potentially useful operations with data: for what generic tasks they can be applied and how to perform each operation with the use of available functions. An example of such an operation is proceeding from absolute values to percentages. This operation is helpful, in particular, in the task of studying proportions (other variants of application are also possible). It is performed with the use of the calculation function of the system.

D) Knowledge about dynamic manipulation facilities available in the system: possible ways of use depending on the analysis context. Here belong the earlier mentioned heuristics about visual comparison with 1 for calculated ratios and with 0 for calculated differences. Another example concerns the application of dynamic classification tool for investigating relationships between one attribute selected as a base of classification and some other attributes for that class statistics is calculated and displayed. A reasonable strategy is to try to increase the number of classes and move class boundaries to probe the robustness of the demonstrated relationship, if any.

E) Knowledge about data and underlying problem domain. This knowledge, besides selection of proper visualization methods, allows to formulate analysis tasks in a way easily understandable by the user. Thus, the generic task "Local estimation of proportions" may have a formulation "Consider proportions of age groups 0-14 years, 15-64 years, 65 and more years in population of each country of Europe" or "Consider proportions of classes of industry *X*, *Y*, ..., *Z* in overall industrial product of main cities of Germany", depending on the application domain. The knowledge about data is used in automatic application of such system functions as calculations, querying, classification according to the pursued analysis scenario.

The utilization of these kinds of knowledge for generating guidance proposals on different steps of user's work may be governed by rules with following structure:

IF [*applicability conditions*] **THEN** [*recommendation*],

where

[*applicability conditions*] may include one or more of the following:

a) required data characteristics and relationships;
b) characteristics of currently considered presentation;
c) currently pursued generic task;

[*recommendation*] may be either one or more generic tasks to proceed to or a hint concerning the use of dynamic map manipulation facilities.

4. Conclusions

Presentation on maps with following visual investigation plays a very important role in analysis of spatially referenced data. We offer an environment that supports the analysis by automation of map generation. Furthermore, the generated maps are not mere static pictures but subject to manipulation and can dynamically change that potentially can make interesting features of data distributions more prominent.

In map design the system relies upon conceptual knowledge about data under analysis. Such knowledge need not to be very extensive, but for each application of Descartes a formalized description of the application domain (relevant notions and relationships IS-A, PART-OF among them) and the database structure (correspondence of database fields to domain notions) should be provided. The utilization of domain knowledge can be substantially extended. We have shown that on the basis of this knowledge the system can offer an intelligent guidance to the user in the course of data analysis.

The dynamic map manipulation facilities available in the system are rather innovative, and therefore there is a probability that even people experienced in the use of maps (or GIS) for data analysis will not try to actively use them. Therefore we consider it necessary also to give the user apt hints concerning the employment of the dynamic facilities in analysis.

Though it is impossible to guarantee interesting findings in any data, we believe that further development of the intelligent capabilities of the system will make it more helpful as an environment for visual data exploration.

Selected publications:

Knowledge-Based Support for Visual Exploration of Spatial Data. *Extended Abstracts of Int. Conf. CHI'97* (Atlanta GA), ACM Press, pp.16-17

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Intelligent Visualization and Dynamic Manipulation: Two Complementary Instruments to Support Data Exploration with GIS. *Proceedings of AVI'98: Advanced Visual Interfaces Int. Working Conference* (L'Aquila – Italy, May 24-27, 1998), ACM Press, pp.66-75

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Introduction

Maps compactly represent geographic information and relationships. Over the course of centuries a set of symbolic conventions have been established that enable cartographers to encode meaning in maps so that individuals with an understanding of symbols (cartographic and others) can decode and use this stored information (see, for example, MacEachren, 1995). With the revolution in cartography that has occurred as a consequence of the widespread use of networked digital computers, the representational conventions of cartography must be extended and re-conceptualized. However, a considerable amount intellectual, social and political baggage has been dragged along as map production has been transformed from the analog to the distributed digital realm. Some of this baggage has now become cumbersome given the rapid pace of improvement in visualization technologies, such as immersion, that are now accessible to a large and growing cadre of researchers. The purpose of this short position paper is to initiate a tenuous and tendentious argument about the use of maps and other geographical representations to gain insight into the nature of complex dynamic phenomena. A particular experiential framework, abduction, is used to motivate the position I adopt.

2.0 Abductive Inference

Abduction is a philosophical framework that has attracted the attention of researchers in the field of artificial intelligence, especially in contexts related to diagnosis, learning and understanding. Josephson & Josephson (1994:5) describe abduction as "inference to the best explanation" and assert that this form of inference goes from information that describes something, to a hypothesis that best explains the information. In general, abduction mirrors those processes that are often used when humans are presented with novel environments and situations. In such cases we often draw upon our experiences and match the current situation to what we have experienced in the past. Stated differently:

I is a collection of information (facts, observations).

H explains *I*.

No other hypothesis can explain *I* as well as *H*.

Therefore, *H* is probably true.

I is information that is derived from a specific visualization of geographical phenomena. Consider, for example, an animated sequence that depicts the spread of a contagious disease within an urban system. If an individual were to examine such an animated sequence and, if they had prior knowledge about the process of disease transmission through a population, then without any textual identification (a map title or legend, for example) about the thematic content of the map they might be able to infer that in this particular case they are observing just such a process. By also noting rates of change in different areas and by coupling this derived information with other facts about, for example, the underlying geographical characteristics of an area (e,g, barriers such as canyons, water bodies and settlement patterns) then it is also likely that they could provide a reasonable assessment about the course of the spread of the disease.

Clearly, however, abductive inference is not foolproof. Josephson and Josephson (1994) argue that since induction is subsumed by abduction, it is possible, therefore, to fall into the same types of logical traps that are demonstrated time and again in introductory logic textbooks: As we move from the specific to the general (induction) it is possible to draw conclusions that are incorrect (the illustrative syllogisms usually involve {birds, feathers, flight and penguins}; or {cats, tails and manx cats}). However, if the process of inference is guided or constrained then induction and abduction can be used to understand learning in complex dynamic environments. Holland *et al.* (1986) assert that the "central problem of induction is to specify processing constraints that will ensure the inferences drawn by a cognitive systems will tend to be plausible and relevant to the system's goals." Constraints may be based on collections of ancillary rules or facts that condition abductive processes. It then follows that abductive processes of map visualization are context-dependent and must necessarily have some feedback mechanism in place so that current knowledge can be altered (e.g., corrected, enhanced) as a consequence of visualization.

3.0 Steering the Abductive Process

If we wish to develop representations and visualizations of complex dynamic geographical phenomena, then it is imperative that we extend the knowledge frameworks that have been developed about static maps. Dynamic maps can be made persuasive and coercive with the power to lead individuals along a particular trail of pursuit. We need to better understand how humans use dynamically mapped information. Are they subject to "overload" and do they then shut down? Do they optimize information acquisition or do they "satisfice"? Peterson (1995: 27) (based on the work of others), for example, describes some basic "limits" of the human cognitive system that might be useful to consider. Other concepts that may prove useful are employed by Smith (1984) and Smith *et al*. (1982) : perceptual buffer, short and long-term memory. Another area that may be fruitful to pursue is the work that has been done in the area of artificial learning systems with dynamic visual inputs (e.g., Holland *et al*., 1986). Such systems are adaptive to the inputs received. Do humans react in similar ways? What inputs are used and what need to be provided to the user to persuade? What role does "forgetfulness" play in such processes?

With the advent of new visualization technologies that promise to become commonplace during the coming decade, other factors will need to be considered. Immersive visualization environments have their own, and not fully understood, elements. Consider for example, a virtual model of an urban area that is designed to support decisions about development and permitted uses. At the present time decisions may be made based on the visual impact of a proposed project. In a virtual model users can navigate and visual impacts can be seen directly. But what if the data have, by accident or design, been shifted slightly, so that objects in the virtual environment can be seen (or not) from a particular position that cannot (or can) be seen in the real environment? Are the ideas that have been developed to support map accuracy applicable to virtual environments? Caveat emptor…

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Cognitive models of dynamic phenomena and their representation: perspective on aspects of the research topic

1. General questions related to the research topic

Important questions for the investigation of the topic (from my perspective) seem:

Which factors influence the kinds of dynamic phenomena that are being observed in reality?

Factors that have to be considered include: purpose of observation, application (discipline), phenomenon being investigated, the ability/expertise of the observer, scale of observation, time frame and resolution considered, whether observations are direct or indirect (e.g. depending on registrations of measurements), and perhaps more factors.

Which kinds of dynamic phenomena are being observed in reality?

The above mentioned factors have to be taken into account to answer this question.

How do observers conceptualize these kinds of dynamic phenomena?

In other words, how do dynamic phenomena influence reasoning, understanding, decision making? Are there systematic differences among observers, and if so, can these be explained from the factors that influence observation mentioned above?

Can the dynamic phenomena observed in reality be categorized, based on the ways in which observers conceptualize them?

Which factors influence the kinds of dynamic phenomena that are being observed in a (graphic) representation of reality?

Most of the factors mentioned above are applicable here as well, except for direct/indirect observation. In addition, scale/resolution of the representation and the data processing and visualization methods applied can be mentioned here.

Which kinds of dynamic phenomena are being observed in representations?

The above mentioned factors have to be taken into account to answer this question.

How do observers conceptualize these kinds of dynamic phenomena?

In other words, how do observers (or in general people) react to different (graphic) representations of dynamic phenomena? Do different displays trigger different kinds of memory, reasoning or decision making?

Can the various (graphic) representations, depending on the way in which people react to them, be matched to ways in which the dynamic phenomena observed in reality are conceptualized (and perhaps classified in topologies)?

If that is possible, it may yield better representations of dynamic phenomena than the ones that are currently used.

2. Direct versus indirect observation of dynamic phenomena

I will further elaborate on a specific aspect mentioned in relation to the questions above. Many dynamic phenomena cannot be *directly* observed in reality by people, but only *indirectly,* through registrations of measurements. This is the case where the dynamics are too slow to be noticed (e.g. geological processes), where they are hidden (e.g. taking place in or under the earth's surface, like certain soil processes) or where they are only reflecting in parts of the spectrum for which human vision is not sensitive (e.g. reflections in the near infrared part of the spectrum).

Remotely sensed data are an important source for spatio-temporal applications, of which the influence will only increase in the future, when data can be acquired at higher spatial resolutions and with more sophisticated methods. In many applications of remotely sensed data, people are relying on indirect observations. Remotely sensed data, however, may be pre-processed before they reach the user. Interesting questions are: if people have to rely (partly or entirely) on indirect observation of dynamic phenomena in reality, does that lead to the adoption of different conceptualizations of the phenomena than the ones conceived by direct observation? How are these conceptualizations matched to reality? Is it possible to design (graphic) representations of the dynamic phenomena (or visualization tools) that facilitate the conceptualization and the matching to the dynamics in reality?

3. Example of indirect observation: NDVI data

One type of data that I intend to use in my Ph.D.-research is NDVI data. NDVI stands for Normalized Difference Vegetation Index. The data are mainly derived from NOAA satellites, which carry sensors that detect emitted radiation in several bands of electromagnetic spectrum, including the red (RED) and near-infrared (NIR) channels, where radiation from green leaves is strongly represented. Healthy vegetation reflects particularly well in the NIR-part of the spectrum[1].

The measure is also referred to as greenness index. It is an indication of the level of photosynthetic activity in vegetation: the more the photosynthesis is going on in green plant material, the higher the NDVI values. The values are used as crude measure of vegetation health, but they vary considerably. Because of the high temporal frequency of teledetection by the NOAA satellites, NDVI data are widely used for the monitoring of vegetation dynamics, e.g. for range land monitoring, pest and disease monitoring and food security programs. The data are particularly useful in otherwise data-poor environments, like developing countries. Data costs are relatively low or even irrelevant, since dekadal images (showing ten days averages) are freely downloadable from the Internet.

The data are pre-processed by NASA before they are made available to other suppliers or users. Users can import image data (showing ten days averages, or images that are composed using the maximum NDVI value for every pixel per day, over a week or month) into application software for time series analysis (e.g. WinDisp3). They usually start with visual inspection to determine the fitness for use (e.g. completeness, cloud problems). For exploration and analysis purposes, these data are often further processed: classified and/or statistically/mathematically analyzed. The results of the calculations are represented in graphs and images. Usually, the representation in images is a static one, although there may be a film mode available in the application software, but the design and user interaction possibilities in this mode are limited.

[1] **NIR-part of the spectrum**: The index is calculated as: NDVI = (NIR - RED)/(NIR + RED), and normalized to the theoretical range -1 <= NDVI<= 1 (to partially account for differences in surface slope and illumination), but realistic values (excluding values for water, soil, noise etc.) range from about - 0.1 (not very green) to 0.6 (very green).

In this example, several of factors mentioned in relation to the kinds of dynamic phenomena observed (see questions above) are known or approximately known (e.g. purpose of observation, application, time frame and resolution considered). Among the factors that are not known are the effects of the way in which the data are processed, classified, modeled and graphically represented. This influences which dynamic phenomena are seen, and the way in which these phenomena are conceptualized.

Therefore, more specific questions related to the monitoring of NDVI data and to my research on cartographic animation for monitoring are:

Which dynamic phenomena are considered to be relevant for monitoring in reality?

Or: which dynamic phenomena is the expert looking for in reality?

How are the dynamic phenomena that are considered relevant related to later evidence in reality?

Consequences of indirectly observed dynamics may ultimately become directly visible in reality, but then it may already be too late to intervene in case of undesired developments (e.g. famine because of crop failure). Still, it may be relevant to be able to verify what kind of dynamics took place.

How do experts conceptualize the dynamics that are considered relevant and how do they match it to later evidence or to reality in other ways?

Which of the relevant dynamic phenomena can be captured from (graphic) representations, After which processing and in what kind of visualization?

How are the dynamic phenomena captured from (graphic) representations conceptualized?

Which of the relevant dynamic phenomena can not, or difficulty be captured from representations?

Are (for the application) new forms of visualization valuable for the monitoring of NDVI data? E.g. can dynamic visualization variables in cartographic animations be applied to facilitate monitoring? A user might be able to work in other ways with animated representations of the data (e.g. instead of calculating absolute or relative differences between pixel values in consecutive images, and displaying the results of two or more calculations juxtapositioned, the original images can perhaps be shown in an animated sequence. In a shorter time span more images can be viewed, and a different, perhaps unusual perspective may reveal other phenomena. For exploration/hypothesis generation about dynamics, unusual perspectives can be stimulating. It is, however, necessary to know in what way people react to different representations, e.g. to (pseudo)motion in images, before this question can be answered.

Can the various (graphic) representations, depending on the way in which people react to them, be matched to ways in which the dynamic phenomena are conceptualized?

The research will require an interdisciplinary approach, in which at least cognitive scientists, vegetation scientists and cartographers/geographers should be involved. The research can be a part of broader, comparative investigations, in which all kinds of factors are involved that influence which dynamic phenomena in reality and in representations are observed (see section 1 of this appendix). If that is done, the following question can be answered:

Are the findings only valid for particular applications, data and problem contexts, or are they broader applicable?

The main purpose of the investigation is to be able to apply functional (graphic) representation methods/tools. The representation and the interface should, as far as possible, match human reasoning and intuition. If this succeeds, workers with geographic data may be able to better capture dynamic phenomena from representations. They may also need less training to work with the data.

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Navigating and Retrieving Information in Web Browsers

Usage tracking has provided us with evidence that hotlists, bookmarks and favorites folders are the navigation tools most frequently utilized by users for locating information on the web (Pitkow & Recker, 1996). Usability studies, as well as basic research, however, indicate that the current designs for navigating the web are sub-optimal in supporting users' cognitive models of web spaces and the information they repeatedly consume (Abrams, 1997; Tauscher & Greenberg, 1997). The Tauscher et al. and Abrams studies were pivotal in that they were among the earliest attempts to gather information about what users are doing while they traverse the web over time, given current browser user interface designs. More recently, others have attempted to track web usage patterns and provide visualization tools displaying this traffic in an effort to provide users with interaction histories of web usage (Wexelblat, 1998). In each of these cases, the documentation of usage patterns has been extremely useful as new ideas for browser designs are explored. Still, one area left virtually unexamined has been the user interface design characteristics that are optimal for leveraging how people remember their interactions with web pages. In addition, understanding what information visualizations leverage this interaction memory is critical to the effective design of the next generation web browsers.

Given what we know about human episodic and semantic memory (Tulving & Thompson, 1972), we can leverage memory for "events" or episodes in browser design, as well as memory for related facts and meanings about those events. A few have studied the contribution of spatial location memory to document management (e.g., Jones & Dumais, 1986), although those results were somewhat inconclusive in how generablizable they are to electronic worlds. Applying human memory theory to the study of memory for favorite web pages, we predicted that many kinds of information about a web page might be stored in long-term memory, including memory for spatial location. We hypothesized that users may remember where they stored a page, what the page looked like, the overall gist of the page, or the title of the page. Users may also know what they were doing when a web page was stored, or the context in which a web page was studied. This is research actively being addressed by Hightower, Ring, Helfman, Bederson, & Hollan (1998), and Wexelblat (1998). They describe the increased efficiency and user satisfaction that can be attained by augmenting browsers with additional usage and image information. For example, Hightower et al. (1998) added a graphical history-map to a browser as a companion tool to aid users as they navigated during search tasks. With "PadPrints", as the tool was called, users visited reliably fewer web pages during search, found their search targets reliably faster, and rated the user interface as more satisfying along a number of dimensions. Since the tool included graphical, temporal and hierarchical detail, it is still unclear which dimension was contributing most strongly to improved user performance and preference. Therefore, we decided to explore more closely what users remember after a brief encounter with a web page in a variety of simulated browsing sessions.

We observed users interacting with Microsoft's Internet Explorer v. 4.0's (IE4) Favorites text-based system, as well as several new, 2D and 3D visualizations of Favorites lists and browsers. Favorites mechanisms allow users to store personally interesting web page addresses locally on the user's machine. It was hoped that, by examining users' navigation performance and memories for these web pages, we would be able to better prioritize which cues might be added to next generation browsers to support efficient search and navigation.

When users go to select a page from Favorites they may only have limited information in short-term memory about the contents and context with which that page was viewed and stored. Users may remember where they stored the page, the name of the page, what the page was about, or perhaps what the page looked like to some degree, but probably cannot recite back the entire contents of a web page. Therefore, we have carried out studies examining what specific attributes of a full web page are efficient retrieval cues. We were also interested in the number and types of categories users would come up with when storing these pages—would there be deep, narrow structures or broad, shallow hierarchies in the resultant organizations? Also, how much intra-subject consistency would there be in terms of the category labels assigned to these structures? Do 3D visual cues benefit navigation and subsequent retrieval performance? Do automatic categorization hints help? The answers to these questions could be used to improve future versions of web browsers.

The combined findings from several of these on-going studies have told us much about what features to add to next generation browsers to benefit users' navigation and retrieval capabilities. For instance, the title and the image of the web pages were both effective retrieval cues, as were other subjects' categorization schemes. Allowing subjects to manually lay out their web pages in a 2D or 3D space is effective for both navigation and later retrieval, even up to six weeks later. It is our belief that users' spatial location memory benefits from this manual layout of the web pages. We found that supporting a combination of explicit/implicit query + navigation in the user interface was a potent addition during information storage and retrieval. Interestingly, there is a large degree of overlap across subjects and their categorization schemes, suggesting to us that a default categorization scheme could benefit navigation in 2D or 3D space. We have experimented with a variety of 3D perceptual cues in our browser research, many of which have contributed significantly to navigation performance. For instance, 3D spatialized audio was a rich cue for efficient navigation and storage of information in 3D space.

To improve web browsers, we have shown that facilities need to be added to allow the user to retrieve pages on the basis of summary information and/or visual cues (adding "scent" to an existing navigational structure). A common problem for retrieving a page on the basis of summary information was that the hierarchy the user created was not cross-referenced. A specific example of this was when one user classified the "Wall Street Journal" web page into a financial category. At retrieval time the user expected to find the page in the news category. One way of recovering from this type of error would be to add an implicit query feature to the Favorites mechanism. When the user selects a page, all the pages that are semantically similar to the selected page would become highlighted. Figure 1 is an example of how this could be done. In the figure the NASA Home Page was the selected item, and it revealed US News and World Report as a related page. In such a mechanism it would be likely that all of the pages belonging to the same section of the hierarchy would be marked as relevant, in addition to relevant pages that happen to have been placed in other, more distantly related parts of the hierarchy.

Figure 1: Implicit query incorporated into the Favorites mechanism

The results of early studies on text-based Favorites storage facilities indicated that users had more difficulty retrieving pages on the basis of a visual cue than by any other cue included in this study. While it might be slightly unusual for a user to try to find a page on the basis of visual appearance alone, some version of a page's image could be a valuable tool for retrieving a page in conjunction with other information. Figures 2 and 3 are a couple of examples of how this could be done in the current Internet Explorer browser. In Figure 2, a thumbnail image exactly the same size as the current title information is placed to the left of the title. In Figure 3, the thumbnail images are made slightly larger so that the page text becomes more legible. The images in this figure are interleaved so they take up no extra vertical room.

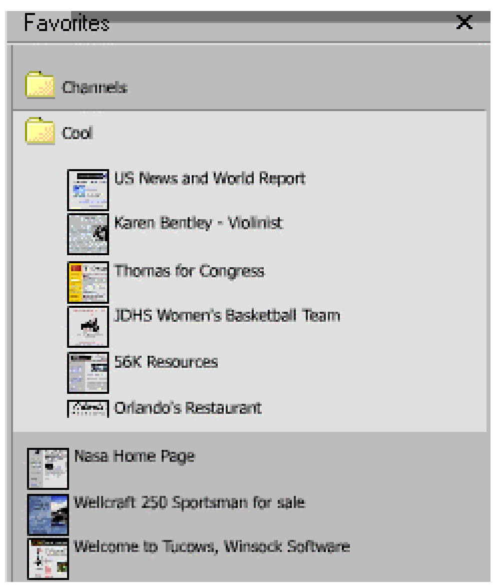

Figure 2: Small thumbnails incorporated into the Favorites mechanism

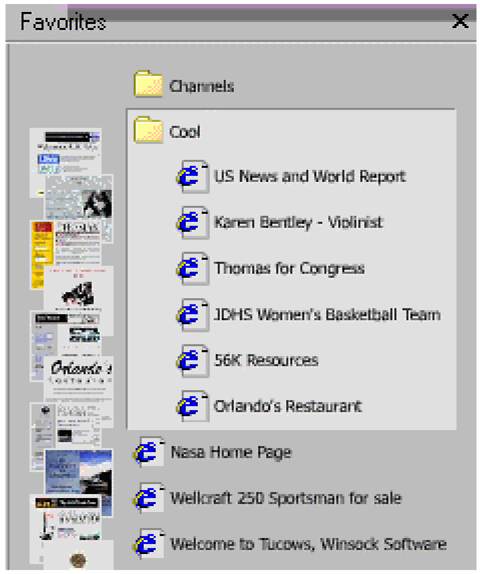

Figure 3: Larger, interleaved thumbnails incorporated into the Favorites mechanism

We have argued that, in order to assist users in managing their important personal web pages, support for the ability to retrieve a page using any of the cues that a person may maintain in long-term memory should be built into the user interface, including spatial memory. We believe that adding support for these cues in the next generation browsers will enhance a user's likelihood of navigating to and finding stored information. Current work in our lab continues to explore adding these mnemonics to the user interface, including an in-depth exploration of the use of spatial cognition as a potentially important aspect of memory that can be leveraged in user interface design.

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Position Statement

In order for us to better understand how to solve navigation problems in virtual environments, it seems obvious that we need to understand more about how people navigate in the real world. In some ways, however, this point isn't so obvious because VEs can be so vastly different from the real world that it could be argued that we're talking about a different animal altogether. I disagree with this position in that people live in the real world, our navigation skills and strategies are born in the real world, and therefore if a VE does not leverage this real world foundation, then the task becomes so abstract that it cannot be performed at all. Consequently, we are keenly interested in how people acquire spatial knowledge and how that knowledge might be represented in memory for use in navigation tasks. While we often use VEs as a tool for study, our interests are in the general issues behind spatial cognition and how individual differences, environmental differences, and interactions with an environment affect navigation.

It seems apparent that individual differences play a major role in spatial knowledge acquisition. In addition to effects due to spatial abilities (e.g., mental rotation, visualization) which I will not discuss here, we have seen a great variety of strategies attempted in many of our environments. These strategies are clearly affected by past experience as well as the task and environment in question. There is a key element here that I have yet to see appear in a clear form in the literature. This has to do with confidence; confidence in one's own skills and capabilities, and confidence in the available tools (e.g., maps, GPS, etc.). Individual differences in this one area are so vastly different that I can safely say that a large part of the variance we see in performance in some of our navigation tasks can be traced directly to confidence.

Case in point, a Marine with thirteen years experience in the field attempts an intermediate level sport orienteering course and succeeds in finding only one of nine targets in a full hour. For comparative purposes, in the same experiment, we had an Air Force Cadet with absolutely no field experience complete the entire course with time to spare. How can this be? Certainly the Marine is not such a poor navigator that he cannot do this task. In post trial interviews, we discovered that entering the task, he had a very high level of confidence in his ability to perform this task. He had some ballpark estimate as to how long he expected it to take to locate the first target, then the second, etc. As he made error upon error, and the time in which he expected to find the first target came and went, his confidence began to waver. Initially, he tried to place blame on the map. He commented on how the map was "wrong" or was missing important items. The monitor (an experienced Army Infantry officer) replied that he was absolutely certain that the map was correct. Later, the Marine began to question himself and his own abilities. There is no doubt that one officer performing very poorly on a task he should have been very good at in front of his peer also had an adverse effect. But as a person begins to question what he knows about a space and consequently, his ability to do the task at all, performance plummets. Why this happens and how it can be alleviated, possibly through familiarization in a VE, is a topic of interest to our group.

The next topic I want to touch on in this position statement has to do with the effect environment has on strategy and consequently, spatial knowledge acquisition. Being adept at navigation in one type of environment does not guarantee good performance in all types of environments. Yet, we have seen individuals who excel in navigation tasks no matter what the environment might look like (at least as compared to a group of individuals). This is true even when spatial abilities are not a factor. It is clear that some people approach navigation problems in a more coherent, environment independent fashion, while others learn the keys to success in one type of environment only. These differences can be highly sensitive. A number of world-class orienteers from the San Francisco Bay area orienteering club came down to Monterey to participate in our first study in natural environments. Some of them noted how their performance was not what it typically is in their own area because the vegetation in Ft. Ord (our testing area) is different from what they are used to. This had an adverse effect on their strategies. For example, some planned routes through coastal Chaparral (not a good idea) or were surprised at the height of some of the Oak forested areas. Others from that group were not affected at all. Their strategies did not depend on vegetation or richness of contour. Our interest here is in determining what makes an approach environment independent and determining if this is a trainable skill.

The last part of this has to do with the actual interface to the virtual environment. It is well known that spatial knowledge acquisition is affected by travel mode. That is, spatial information I attend to when on foot is different from when I'm on my bicycle, which is in turn different from when I drive my car, which is different from when I'm a passenger in a car. This topic becomes more confused when we introduce interfaces to VEs which often break all the rules of physical reality. The effects of interfaces on navigation are largely unknown. Unfortunately, most of the attention has been given to maneuverability issues of VE interfaces. While it is important to be able to get from here to there, it is equally important (if not more so) to understand what "here" and "there" are and what the spatial relationships are between them. These, also, are affected by the interface, often adversely.

Most of this position statement has dealt with spatial knowledge acquisition. However, we are really interested in the bigger picture which also includes spatial knowledge representations and the use of this knowledge in navigation tasks. We have been trying recently to construct a model of spatial knowledge representations based on our work in natural environments. It is obvious to us that the flat landmark, route, survey knowledge (LRS) construct is oversimplified. There clearly is some hierarchical construct at work here. Attempts to use cluster analysis on route planning and execution in natural environments have thus far been unsuccessful. However, we believe that proximity between targets causes clustering to occur in some fashion resulting in high performance within a cluster and poorer performance between clusters. Thus far, we have not been able to show this consistently, at least to our satisfaction.

The last item I will discuss in this statement has to do with disambiguation of junctions. In orienteering, we refer to a "parallel error" as an error made when the orienteer thinks he is in one place that is spatially similar to where he actually is. This usually occurs at junctions. One of the reasons why problems occur with maps is that there often is no information by which to disambiguate two junctions. If we went there and looked at each junction, differences would appear, but they are not readily apparent from only the map. We think this is where a VE can be a useful tool. This actually falls more into the category of landmark knowledge than anything else. It has to do with recognizing a place correctly given whatever information is available. However, even in participants who perform our tasks very well, we do not yet understand how this disambiguation takes place. What do they encode and recall that works for them? Why do other fail where they succeed? Do both successful and unsuccessful participants recognize the junction as a unique place or does one or the other use it as part of a path between two other points? We believe that an understanding of this issue will lead us toward a more accurate model of human navigation and consequently, a better understanding of navigation in VEs.

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Research abstract on dynamic phenomena in space and their representation

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1. On Change and Motion

The conception of time and of temporal structure are strongly influenced by our perception and conception of changes in the world. If the world did not change, there would not be a reason to distinguish and talk about different times. Changes in and to the world can be conceived of as discrete or continuous. The *discrete conception of change* focuses on the difference between the situation before and the situation after the change or the boundaries of the change. The *continuous conception of change* focuses on the course of change, the development of the situation while the change goes on, and the internal structure of the change. I will call the discrete conception the *event view* and the continuous conception the *process view* of change. The event view of motion, for example, relates the starting position and the final position of the moving object. Direction and velocity of movement can in this view only be described on a global level, relating starting position and final position and the time of its beginning and its end. In contrast, the process view emphasizes the path or trajectory and the process of change along it. Direction and velocity can be ascribed locally with respect to any sub-period of the time of the process.

As a basic characterization of the event view of simple change I take that a proposition is true at one time and false at another time. More complex cases of change involve a periodical re-establishment of states.

In the informal uses of the term 'continuity', developments are said to be continuous if they are smooth, which can be specified by: no interruptions are noticeable (they do not stop in between) and no jumps are noticeable (there is some constancy to the change). This informal characterization allows two uses that are observable: one that allows for periods of constancy in the underlying structure (e.g., continuity in leadership) and one that asks for a constancy in change (continuity in progress).

In the event view, motion can be characterized by the contrast of a starting position and a final position. Discrete motion can be a jump between these two positions not involving any position in between. An example of this kind of motion is the change of habitation.

The process view of motion needs to refer to more places than just the starting position and final position. One reading of continuity (monotonicity in change or constancy in development) can be characterized based on a binary relation. It expresses the condition that places traced in a given order by a moving object are correspondingly related.

For a more specific account to continuity of motion we must be able to specify that immediate 'jumps' in space are not noticeable. That is: small changes in time result in small spatial changes. The main problem for giving a more systematic account is to define a measure for difference of regions and the topology for spatial traces of extended bodies (cf. Galton, 1997)

Another problem of continuity can be observed if we consider the material bodies that move through space not only as wholes but also regarding their part-structure. The continuity in body-movement or the rotation of a ball also includes that the parts of the whole change their positions relative to each other in a smooth manner. My left arm and my right arm do not immediately change their relative positions and neighboring segments of the ball stay neighbors.

2. Characteristics and Classes of Motion Based on Spatial Structure

One characteristic class of spatial changes of material bodies is the movement through space along a way, path or trajectory. Our movement from home to work or back again is easily considered as such motion, but also the movement of the earth around the sun or the movement of the moon around the earth, i.e., rotation around a center outside the body. In contrast to this, bodily movements like waving my arms or turning my head and rotations around inner centers like the earth's rotation around its center are not as clearly motions along trajectories.

Although our examples of movements along trajectories involve the other kind of spatial change, it seems that we can easily conceptualize the spatial change a material body undergoes as purely trajectory-based. This is, e.g., also reflected in the coding of spatial change in natural language, where differences between verbs that encode trajectory-based movement and modes of (internal or bodily) movement can be observed.

Trajectories of moving objects are generally conceived as linearly structured. Movements through space of individual bodies therefore provide diverse options to linearize space. Accordingly, the individual positions the material bodies assume in the course of motion are points in space. This basically means that the internal spatial structure, the shape and spatial extension of the body are considered irrelevant in the conceptualization of its movement through space. Since points do not have spatially distinguished parts, point-like objects can only move by changing their position completely. Thus, if other kinds of motion are accounted for, then the objects have to be conceptualized as spatially structured or extended. Motions that are not conceptualized as trajectory-based like body movement and rotation around an internal center always take the existence of an internal spatial structure of the objects into account.

Considering the trajectory and the motion along it means to consider the process view of spatial change. Additionally, this kind of movement is paradigmatic for our idea of continuous movement. Trajectories are spatially embedded linear structures and movement along trajectories is continuous if the trajectory is spatially continuous and the movement along it respects its spatial order (cf. Eschenbach, Habel & Kulik, 1998).

In contrast to trajectory-based motion, the main characteristic for pure internal motion is that the positions occupied by the body in the course of the motion do overlap. Most characteristic are movements in which a certain spatial region is occupied throughout the process. The spatial change responsible for our categorizing the process as motion in these cases are changes of the positions of parts of the objects (that can exhibit trajectories) and—connected to this—changes of the orientation of internally constituted spatial reference frames.

In the group of internal motion I want to include movements that cannot be characterized as change of location of the whole body. It shall include rotations of disks and spheres as well as the motion of fluids in a closed system or bodily movement. Therefore I do not postulate that internal motion is motion of the whole entity but just that it involves the motion of some part of the object.

The class of movements that keep some parts of space constant can be further subdivided. The classes of internal motion we discuss in some detail are growth, shrinkage, internal rotation, the movement of parts and short movements that can constitute trajectory movements.

Growth and shrinkage of entities can be defined by their monotone gain or loss of space of occupation throughout time. Growth is internal motion that results in the gain of space and is monotone in that it never loses any space in the process. Shrinkage is—accordingly—internal motion that results in the loss of space and shrinkage is monotone since the object does not gain any space in the process.

While growth and shrinkage imply that the region occupied in the beginning and in the end differ, some internal movements do not. Examples of such movements are perfect internal rotation of rigid symmetric bodies and the motion of fluids or gases in closed systems. In both cases, most of the parts of the object change place, but some parts—those that are symmetric with respect to the center of rotation—do not change their position. Still, all extended parts have some part that moves. Thus, internal rotation is characterized as internal motion of a body such that all extended parts include a moving part. Consequently, although all parts are in (internal) motion, stable centers can exist. This characterization only describes a relation between beginning and end. For the process view, the correspondence of trajectories of smaller parts of the rotating object can be considered.

The third class of internal motion to be discussed includes body movements and, in general, movements of parts of an object while other parts do not move. Bodily movements consist of movement of parts of the body relative to other parts. That means that those parts change their location while the other parts stay at a location. Parts of a body may change their location in different ways. We will have to consider the cases of parts that move along trajectories (as my finger tip when I wave my arm) and parts that move by rotating around its joint with the body (as my complete arm in this movement). This is taken care of by the formulation of, since it does not specify the character of motion of the moving part.

It is worth noting that partial growth and partial shrinkage is both, growth and partial motion or shrinkage and partial motion, respectively. Thus, the classes given here are not exclusive. Since change of form of objects needs to involve change of object parts in addition to the boundary or surface of the object, change of form is here subsumed under partial motion.

The last class of internal movements to be characterized is the class of short movements of larger rigid bodies that seem to be trajectory based but are too short to result in a complete shift of position of the larger body. In this case, all parts of the object that are small enough exhibit a trajectory based motion, thus, all parts have parts with a trajectory. This kind of internal movements cannot have stable centers.

There are mainly three connections between the two distinguished kinds of movement to be considered in the following. First, several movements are conceived of as combinations of internal movement and trajectory-based movement, like someone's walking or the rolling of a ball down a hill in contrast to a stones sliding. Second, parts of objects may exhibit trajectory based motion, while the body as a whole is moving internally. Thus, internal motion at a coarser grain of space can at a finer grain of space be trajectory-based motion. Third, internal motions in shorter time spans can be combined to trajectory-based motion over longer time spans.

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1. Formats of representation: Pictorial and propositional representations

During the last decades representations, which serve as analogical counterparts to entities, and configurations they model have become to the focus of interest in Artificial Intelligence and Cognitive Science. On the empirical side, research on imagery and mental rotation has given overwhelming evidence for analog representations of spatial configurations, i.e. representations with intrinsic spatial properties (cf. Kosslyn 1980, 1994; Palmer 1978). Such non-propositional representations can be induced by perceptual or linguistic inputs and are used successfully in reasoning tasks. From the knowledge representation and processing perspective of AI, processes of diagrammatical reasoning, which extend the inferential performance of reasoning systems, have demonstrated their importance for the development of systems with a wide spectrum of tasks, e.g., multi-media communication systems, visualization systems in software design or molecular scene analysis. Both Cognitive Science and Artificial Intelligence approaches to diagrammatic representations deal with internal as well as with external representations: on the one hand, there are investigations on spatial mental representations, e.g. mental images (Kosslyn, 1994),mental maps and knowledge about the environment (Montello, 1992; Hirtle & Heidorn 1993) or spatial mental models (Johnson-Laird, 1983) and on knowledge representations with spatial properties, e.g. the computational imagery approach of Glasgow and Papadias (1992), on the other hand, there is research on external spatial and diagrammatic means for processing knowledge, especially on geographic maps, (cf. Bertin, 1981; Monmonier, 1996). The benefits of analog representations - whether they are internal or external, whether they are called pictorial, spatial or diagrammatic - are based on their property of having the same inherent constraints as the domain they model.

2. Representing dynamic phenomenaanalogously

Research on analog representations as mentioned above has a strong bias to the spatial domain. Although processes using analog representations, for example "rotation of mental images" or "zooming and scanning of mental images", have been in the centre of AI and Cognitive Science since nearly 20 years, investigations on analog representations of change and dynamics are only in their infancy (but, a major exception is the "dynamic mental representation" paradigm by Freyd and colleagues, see, e.g., Freyd 1987). External pictorial or analog representations, as maps, pictures, or diagrams, are static. To use them for representing change, movement or other dynamic phenomena some methods have been developed, for example, annotation of entities in maps by temporal information (e.g., dates of historical events or natural disasters), usage of different types of arrows in maps in diagrams, or the technique of representing the development of states in the real world by sequences of representations, e.g. a series of maps or diagrams, in the minimal case, a before-after pair of diagrams. In the technical context of multimedia and the internet it is possible to present information about spatial domains, about geographic space in particular, not only statically but also dynamically. Dynamic visualization will be especially relevant to represent knowledge about change and processes. To understand the processes and representations involved in the use of dynamic visualizations by a user, it is necessary to distinguish at least - the following levels of representations and representational entities (Following Palmer (1978), I assign the represented world to a distinguished representational level):

(1) dynamic situations in the real world, e.g. changes and processes,
(2) dynamic external representations, perceivable on a computer screen (based on representations of dynamic phenomena stored in a GIS or knowledge based system)
(3) mental representations built up by the user, of static or dynamic type.

For the following, I will focus on the process of comprehending dynamic external representations, i.e. of level (2) entities, which I call dynamic maps [This includes geographical maps, as well as sketch maps and diagrams].

2.1 Analog dynamic representationsand the temporal structure of representational levels

Whether a dynamic representation functions adequately as an analog representation depends on the agreement of properties and constraints between the temporal structures of the two levels of representation in question, i.e. of level (1) to level (2) mappings, or of level (2) to level (3) mappings (on analog representations, see Palmer 1978). Some aspects of temporal structure highly relevant for constituting adequate analog representations are:

Topological structure of the temporal domain: discrete, dense or continuous (see, e.g., Habel 1994): Whereas continuous representations seem to be necessary for an adequate dynamic representation of processes and events, e.g. motion, there are also changes, for which only the initial state and the final state are relevant. In these cases, discrete dynamic representations seems to be more appropriate.

Scale and granularity constraints in mapping between representational levels: The mapping between the temporal structures of two levels of representation has to consider temporal scale. This can be performed by a linear mapping, or one with non-linear properties. Especially, the change from normal speed to slow motion or time-lapse motion, has non-linear transitions.

Direction of time: Whereas the forward direction of time is the standard way to present a course of events or a development of states of affairs, backward presentation can be very helpful in explaining causal histories (going from the current state of a system to its precessors).

Up to now, there are only few systematic investigations on the influence of these dimensions of temporal structure on comprehending dynamic maps.

2.2 Layers orrepresentations

A person perceiving and comprehending a dynamic map builds up internal representations (conceptualizations) which refer to both, graphical entities and real world entities. Since the latter correspond to the things a person who designs a dynamic map intends to represent we call them intended entities. Thus, the internal representations of the comprehender of a dynamic map can be divided into four representational layers (see Tappe & Habel 1998):

the layer of graphical objects(e.g. lines, squares, rectangles, ...),

the layer of intended objects(e.g. a campus, the xy-street, a subway station...),

the layer of visualizationevents (e.g. a line appears, a square is highlighted, ...) and

the layer of intended events(e.g. driving on a street, crossing a mountain range, ...).

Empirical investigations (see sect. 3) give evidence, that comprehension of dynamic maps as well as reasoning about such maps is performed by processes, which make use of all layers. Furthermore, the graphical/visualization layers, (a) & (c) are not only intermediate layers; they are also active during processing the intended domain layers, (b) & (d). In other words, some conceptualizations (entities of level (3) representations) are simultaneously representations of graphical entities presented or visualization events performed on a computer screen and of real world objects or events.

3. Conceptualization of Dynamic Sketch Maps - An empirical case study

To investigate the processes of conceptualization during comprehension of dynamic maps we performed experiments in a language production task (Habel 1997, Tappe & Habel 1998). As stimuli we used sketch maps of the route from the computer science department to the main campus of the University of Hamburg. The sketch maps were drawn on a electronic A3 sketch-pad and the drawing process was documented in a computer program that was especially designed for this purpose. In the experiments, the subjects were presented a replay of the drawing events on a computer screen. They were instructed to watch carefully what happened and to describe it. The verbalizers saw pixels appear in a sequential manner—one after the other—on the previously blank computer screen; the graphical objects became visible in the same chronological order that they were previously produced in. The speech data were recorded with a digital recorder; the transcripts were proofread by a second person. Our analyses of the dynamic map presentations are twofold: Firstly, we formalize the graphical entities, i.e. objects and events, in the framework of a ‘sketch grammar’. Such as grammar reflects part of a person’s competence that allows him or her to draw sketch maps and to interpret maps drawn by others. Secondly, we analyze elicited verbal descriptions with formal linguistic and psycholinguistic methods. In particular, the analysis of the language production process leads to insights in the conceptualization processes performed during comprehension of the dynamic map, especially the sub-processes of segmentation, grouping, structuring, and linearization. The experimental design allows to investigate the comprehension of different types of dynamic maps as well as a variety of factors which have an effect on the conceptualization process. Especially, it is possible to make systematic variations of the some of these parameters, for example: (1) In an on-line condition the speakers are instructed to start speaking as soon as the graphical objects started to appear and to describe simultaneously what happens on the screen. In an off-line condition the subjects first perceive the whole genesis of the respective sketch, then the computer screen goes completely blank and afterwards they describe what they had seen. (2) Variation of speed of presentation and difference between continuous presentation vs. presentation of discrete, contentful chunks of information. (3) Presentation of isolated dynamic maps and those presented in interaction with further information:(i) information given before the dynamic map presentation started vs. simultaneously given information, (ii.) visually vs. auditory presented information.

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A Space Syntax Approach to Spatial Cognition in Urban Environments

Abstract Geographic space is a large scale space which is beyond the human perception, and can not be seen from a single viewpoint. Maps and drawings provide one way of perceiving and understanding geographic spaces. Here another approach to spatial cognition is addressed. The approach, space syntax, is proved to be of great value in predicting human spatial behaviour in urban environments. The discussion is instrumental in explaining some previous findings in space syntax studies, and can also be seen as a contribution to Naive geography. The basic assumption is that human spatial cognition in some sense is determined by spatial configuration, and spatial cognition again determines human spatial behavior like pedestrian movement in urban environments. Thus, by analyzing urban morphological properties, pedestrian rates are predictable.

Keywords: Spatial cognition, space syntax, naïve geography.

1. Introduction

Spatial cognition is the human understanding and perception of geographic space. Geographical space is a large-scale space, it is "a space whose structure is at a significantly larger scale than the observations available at an instant. Thus, to learn the large-scale structure of the space, the traveler must necessarily build a cognitive map of the environment by integrating observations over extended periods of time, inferring spatial structure from perceptions and effects of actions." (Kuipers and Levit 1990). Thus, geographic space differentiates from small scale space or 'table-top' space, in which objects are thought of being manipulable or explorable from a single point of view. One could have a global view of the small scale space. Urban environments can be seen as a kind of geographic space either at the architecture scale or city scale.

The traditional view on spatial cognition is said to be based on cognitive maps (Lynch 1960) - a mental map about the geographic space. However, it is generally agreed that the cognitive map is not entirely maplike (Kuipers 1982, pp. 202). Maps are based on Euclidean geometry, i.e. spatial objects are represented with precise coordinates along objects edges or outlines. However, spatial cognition is not necessarily based on metric measures, for instance, spatial adjacency cannot be perceived by a metric measure, as trivial distance difference might exclude a site from a particular neighborhood.

In the context of this paper, a new kind of map called an axial map using the space syntax approach is introduced, which, we believe, has more resemblance to a cognitive map. The axial map, or more precisely the space syntax approach, is well used to predict human spatial behavior both at the architectural and city scale. Therefore the paper is intended to provide cognitive evidence as to why human behavior is predictable using the space syntax approach, rather than how people explore the urban system with an axial map. The basic assumption is that spatial configuration (morphological structure) is the driving force for human activity within urban environments, and it is this that first influences human cognition, and further determines human activity within urban environments.

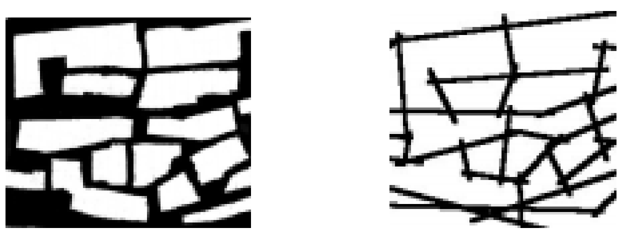
The work presented here is also motivated by naïve geography in the field of spatial information theory, a theoretical basis for GIS. Naive geography (Egenhofer and Mark 1995) is defined as the body of knowledge that people have about the surrounding geographic world. It is considered to be the fundamentals of next generation GIS, which can be used by average citizens without extensive training. Naive geography intends to incorporate people's concepts about space and time and to mimic human thinking.

The remainder of this paper continues with a brief introduction to the space syntax approach used as a powerful tool for urban morphological analysis (Jiang 1998). In the main part of this paper, sections 3 and 4, we elaborate on the plausity of the space syntax approach both as a computational and cognitive model. Section 5 presents our conclusions and points out some directions for further research.

2. Space syntax approach

Space syntax is based on the fact that an urban environment is an interconnected space where everywhere links to everywhere else. The space syntax approach provides an urban morphological representation by looking at only public spaces (open space). These public spaces look like a beady ring system, in which space widens to form irregular beads, and narrows to form strings, while at the same time joining back to itself so that there are always choices of routes from any one space to any other space (Hillier and Hanson 1984, pp. 90).

Based on the analogy of the beady ring system, there are two ways to represent urban environments by only concentrating on public spaces: convex polygons and axial lines. A convex polygon is a polygon that no line drawn between any pair of points within that polygon goes outside of the polygon. The axial line is the longest straight line, which chains convex polygons. Axial lines are said to be also linked to the notion of visibility. Both kinds of representation are named convex maps and axial maps respectively. Figure 1 shows the open space of an irregular street grid and its axial representation - axial map.



(a) (b)

Figure 1: The open space of an irregular street grid (a) and its axial representation (b)

The above axial representation gives the opportunity to measure a particular property of the urban environment; connectivity indexes, control value and integration are some of these morphological properties. Connectivity is the measure of how well an axial line is intersected by others. In principle, there is no non-intersected line in any urban environment, i.e. each space is accessible from every other space in the city. In the mean time, experience tells us that the length of the axial line has some correlation to connectivity indexes, that is, these are more possibilities for lengthy lines to be intersected by others.

A modification of connectivity is control value, which measures how each axial line controls its immediate neighbors, i.e. those lines intersected by the current one. Both connectivity and control are local measures, since they only take into account relationships between a space and its immediate neighbors.

Integration of a line is by definition a value, which indicates the degree to which a line is more integrated, or segregated, from a system as a whole. The measure is actually based on a more basic notion called depth. Depth is more generally a topological distance in a graph. If two lines are directly connected, then the distance between them is equal to one, and the distance of a pair of lines which are not directly connected is the shortest path between them. Integration is a global measure, as the calculation of integration is based on the total depth from the current. However, if a number of depth, instead of all depth, is considered, then the integration is called local integration.

Finally the axial maps can be colored from red through the spectrum to blue depending either on connectivity or on integration. Thus red lines are well connected or well-integrated and blue lines are not well connected and most segregated with spectrum representing something in between.

In summary, global integration is a key morphological variable, and its value of a space can be measured based on the number of other spaces that must be traversed in order to reach all the other parts of the system. Connectivity, as well as local integration, on the other hand, measures local morphological property of a system. In some sense, control value is a modified connectivity measure, which takes into account the connection of each neighbor of a space. Thus, global integration is a global measure describing the relation of each space to the system as a whole, while connectivity and local integration are local measures describing the relationship of each space to its neighbors.

The development of space syntax theory basically consists of two parts: (1) the formalisms of geographic models for urban environments; and (2) the test and analyzing of formal models. The above discussion only covers the first part. As far as the second part concerned, extensive empirical studies have been made over the past decade with spatial syntax research (e.g. Hillier 1997). The rest of this paper concentrates on the computational and cognitive aspects of the model.

3. The computational model of space

You may have sensed from the above introduction to the space syntax that the theory is based on the graph theory, or more precisely that the actual morphological computation is based on the associated graph of the axial map. Figure 2 shows a simple version of an axial map and the associated graph. With the figure, it is relatively easy to understand the morphological measures introduced above. First of all, connectivity is the number of nodes directly linked to each individual node. For instance, line 1 (or node 1 in the associated graph) in figure 2 has connectivity of 3, and line 2 has connectivity of 1.

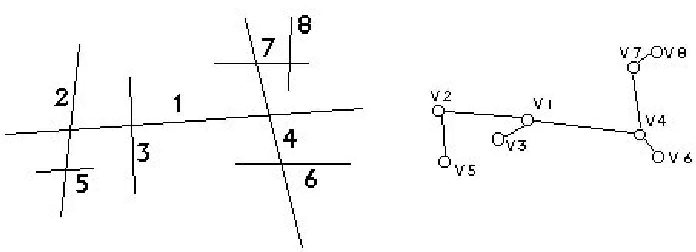


Figure 2: An axial map and the associated graph

The control value for a line is determined according to the following calculation,

$$ctrl_i = \sum_{j=1}^{n} \frac{1}{C_j} \quad \text{............(1)}$$

where n is the number of immediate neighbors of a space, and Cj is the connectivity of the jth immediate neighbor of the space.

According to the definition of depth, for each axial line, all other lines should be traversed in order to retain the so called mean depth (MD),

$$MD_i = \frac{\sum_{j=1}^{n} d_{ij}}{n-1} \quad \text{.....................(2)}$$

where n is the number of spaces and $\sum_{j=1}^{n} d_{ij}$ is the total depth of the ith axial line.

For measuring integration and segregation property, MD is sufficient. Relative Asymmetry (RA) is employed to standardize MD between 0 and 1.

$$RA_i = \frac{2(MD_i - 1)}{n-2} \quad \text{......................(3)}$$

What keeps space syntax a plausible model for spatial cognition is that it is a computational model. In other words, with the computational model by analyzing morphological structure human spatial behavior is predictable. For instance, extensive empirical studies over the past decade have demonstrated that pedestrian rates strongly correlate to local integration value (Hillier et al. 1993).

4. The cognitive model of space

In this section, we attempt to elaborate on some cognitive issues using the space syntax approach, e.g. why human behavior is predictable? Space syntax is also considered as a contribution to naive geography, because it is not only computationally plausible, as shown above, but is also cognitively plausible as discussed below.

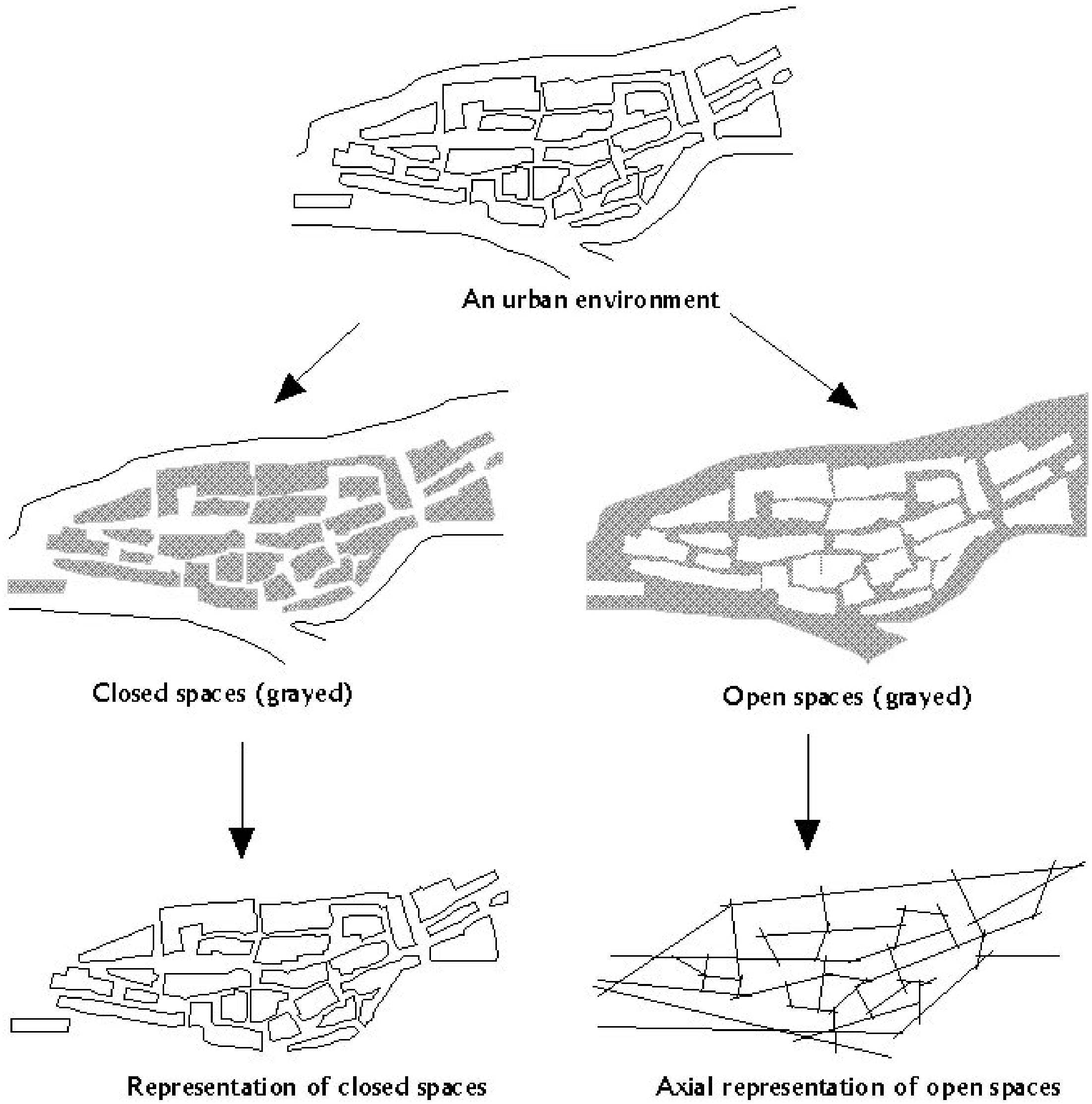


Figure 3: Closed spaces and open spaces

4.1 Closed spaces vs open spaces

Geographic spaces, particularly urban environments, are complex spaces which can be viewed from two stands: closed spaces and open spaces. As shown in Figure 3, closed spaces are spatial entities such as buildings, plots, and street blocks; open spaces are mainly streets. Traditional maps represent geographic spaces both with closed spaces and open spaces in a paper sheet, while GIS represent these spaces layer by layer. Space syntax concentrates on the representation of open spaces in a unique way, which differentiates it from maps and GIS.

Open spaces are all interconnected, one can travel from everywhere to everywhere else. It is this kind of characteristics that keep space syntax in a unique way in modeling urban environments, or geographic space in more general term. From the cognitive point of view, concentration on open spaces at least has following advantages. It is useful to analyze and understand the morphological structure; It facilitates the perception of human activities in urban environments.

One of spatial knowledge is cognitive knowledge, which is essentially ‘map-like’, and includes knowledge of relative positions, distances and angles (Mark 1997). However, we argue that maps are poor in perceiving spatial configuration, while axial maps, a special map based on open spaces, are good in analyzing the morphological properties of urban environments. The study of spatial configuration is instrumental in predicting human behavior, for instance, pedestrian movements in urban environments.

4. 2 Vista spaces vs urban environments

Space syntax starts the representation of urban environments from what can be seen from a single viewpoint. The viewable space is called a vista space, which is represented as an axial line. Thus an urban environment is a set of all vista spaces, and is represented visually as an axial map, or mathematically an interconnected graph. Therefore, the property of an urban environment can be inferred from individual vista spaces. Compared to spatial modeling using Euclidean geometry in which the geographic objects are represented as a series of co-ordinates and spatial inference is based on the complex computation, the space syntax approach is object oriented.

An axial map is an economic representation of urban form, which is a kind of morphological representation. Krafta (1997, pp.2) refers to the kind of morphological representation as a configurational representation, i.e. "a representation of the urban spatial reality given by a few categories of components (e.g. the axial line) and rules (the adjacency) which tie each component to all others in such a way that a change in any one of these basic elements reflects on the entire system". Therefore, morphological representation differs from maps and the like (photographs, or drawings) in the sense that it is a systematic description of urban environments.

Regarding the economic representation, Krafta gave a plausible analogy - "x ray" of urban environments. Axial maps can be seen as the approximate skeleton of urban environments. That is, with the axial map representation, it is possible to think about the basic form of urban environments. For instance, figure 4 shows a series of axial maps of Oxford at different times from the 14 century up to the present, where the gray scale of lines represents the global integration, i.e. the darker, the more integrated. From the figure, the basic spatial morphological structure is readable, for instance where the integrated areas are and where the segregated areas are.

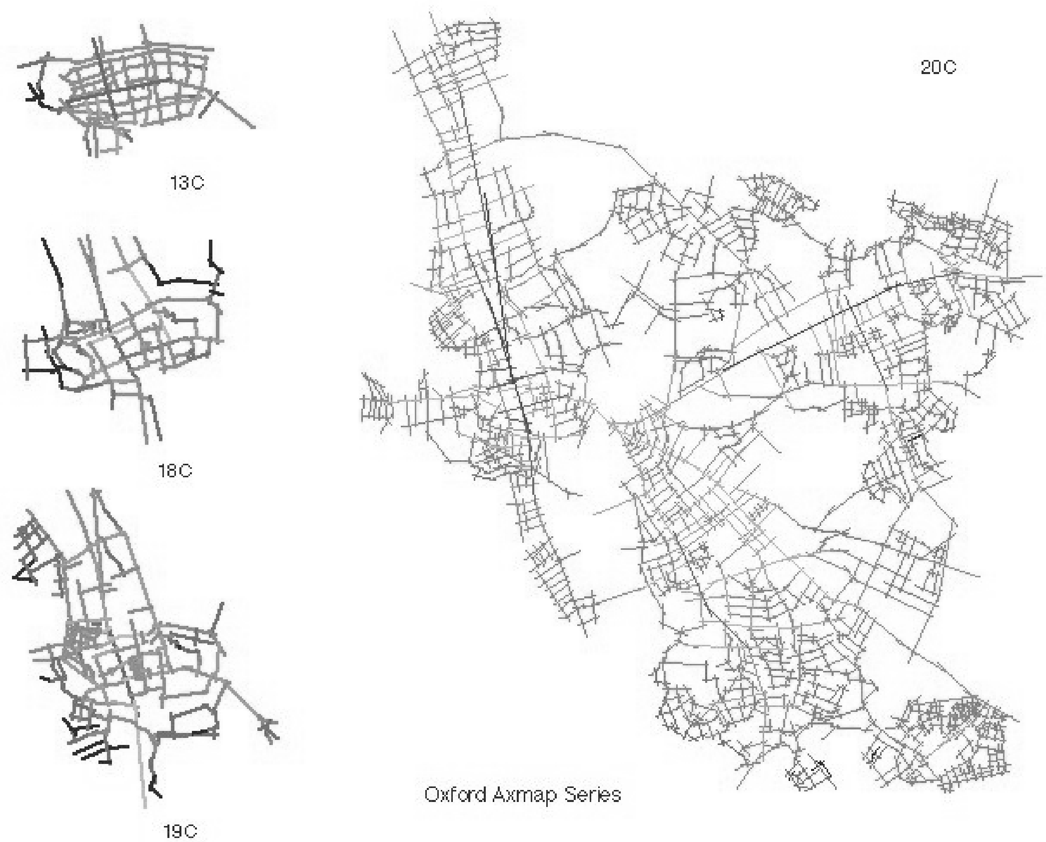


Figure 4: An axial map series of Oxford

The difference between morphological representations and maps, has been rooted in long standing debate, i.e. whether geographic space should be viewed as something measurable with a ruler or whether the only important information is the relationships between objects in that space. Human thinking is not metric based. If you are asked where your home is, you may answer by saying in which region (hierarchical reasoning), and by (topological relation) a certain street. Therefore, topological relationship is frequently used in daily life. Incorporation of this sort of knowledge into a GIS is so called common-sense reasoning. This strikes me to be a possible explanation of how people in general perceive space when they are walking or driving over the urban space, i.e. one vista space is perceived as one unit in human mind, and the urban space is a collection of all vista spaces. With this explanation, it is understandable that pedestrian rates are predictable using the local morphological properties.

Street networks seem to have similar roles as axial maps in structural description, however, we are not convinced with this as named streets are in a sense "artificial". Maps are the most efficient and effective way of communicating metric properties of large-scale space, whilst the axial maps are more likely to resemble human spatial reasoning and perception processes.

4.3 Distance and spatial adjacency

Distance is the central concept of spatial cognition, and it plays an important role in human activity. As stated by Montello (1997, pp. 297), "it helps us orient ourselves and locate places during navigation. It is used to evaluate costs of traveling from one place to another, and it helps us utilize resources efficiently (time, money, food). Clearly, knowledge of distances in the environment ‘effect the decision to stay or go.. the decision of where to go... [and] the decision of which route to take' (Cadwallader 1976: pp. 316). It therefore seems likely that an understanding of the perception and explanation of spatial behaviour."

The distance that space syntax concerns itself with is a sort of topological distance (Buckley and Harary 1990), i.e. the distance of two intersected axial lines is one, and distance of non-intersected lines is the shortest path between them. The paradigm about distance set by space syntax conforms well to cognitive distance. This is summarized as a so called segmentation feature, i.e. routes with increasing numbers of right-angle turns were shown to be psychologically longer than routes with fewer right-angle turns (Sadalla and Magel 1980). Figure 4 illustrates two routes from point A to point B, people in general follow the route with more turns have a longer distance estimate than another route with only one turn. Again this strikes me as an indication of the resemblance between topological relationship to human perception.

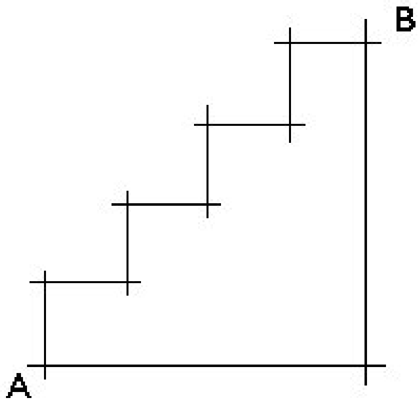


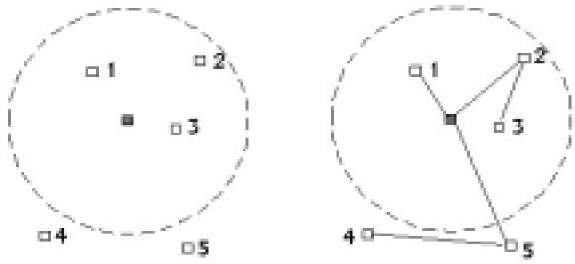
Figure 5: Distance estimates influenced by the route structuring

As the global integration is derived from the mean depth, the mean shortest distance is from a node to every other node in a graph. The notion well conforms to the conclusion in cognitive science that when traveling in an urban environment, the choices of routes reflects the human desire to minimize functional distance (Deutsch and Isard 1961).

Spatial adjacency is a special kind of spatial relationship, and it is a very important feature, which is frequently discussed in current GIS. It is mainly dealt with by computational geometry (e.g. Berg et al. 1997), which is regarded as a geometry for GIS. In raster format, to define adjacency, we must specify a or pixels grid, or we have to intentionally set up topological relationships of spatial objects in vector format. As summarized by Gold (1995) that "raster adjacency is based on adjacent regular tiles - usually squares of space; vector adjacency depends on the detection of line intersection in order to form a polygonal graph and it is this graph that forms the conventional GIS 'topology'".

Space adjacency is a basic rule to form axial maps, i.e. two axial lines intersected are regarded as adjacency. The existence of this adjacency relationship is expressed as an edge of the dual graph. This edge connects two nodes, each node representing a vista space.

Spatial syntax seems to be reasonable in measuring spatial adjacency. Space adjacency can be measured with metric distance, for example by drawing a circle around a point object, or drawing a buffer along a line or polygon object. If a spatial adjacency is modeled metrically, then the trivial distance difference may exclude a site from the neighborhood. Thus, metric measure is a poor measure for spatial adjacency as shown in figure 6. In terms of metric distance points 1, 2 and 3 are neighbors of the central points. However, when considering connection, point 3 is excluded from its neighbors because of poor connection, while point 5 is included in the neighbors. We believe that the neighbors in the right hand are more realistic. There has been increasing attention to solving spatial adjacency from setting appropriate (topological) data structure (Okaba 1994, Gold 1992).



a: metric space b: topological space

Figure 6: The concept of neighbor in both metric and topological space

Now coming back to space syntax, it is understandable that people living by the dominated street may have relatively bigger neighborhood feelings and in the opposite way, the people living in less dominated streets may have less neighborhood feelings. This may be a basic hypothesis, which needs to be investigated in the future.

5. Summary and Conclusions

In spite of the fact that spatial cognition is an important aspect of GIS, and that there has increasing research activity in this respect, no satisfying model for the prediction of spatial behavior has been developed to date. This paper provides such a model that shows that human spatial behavior in general is predictable in urban environments. Extensive empirical studies have been made over the past decade at Bartlet School of Graduate Studies, of University College London in this field.

Configurational representation of urban systems (or more generally geographic space) is a sort of representation which differentiates it from other visual representations we are used to. Maps and the like are a kind of metric representation which do not result in more information as far as spatial cognition is concerned, whilst configurational representation based on topological relationships may be more informative in the sense of spatial cognition.

Space syntax provides an alternative way to understanding geographic space. The distinguished property of space syntax is the same as that of naive geography, i.e. treats topological relationships as prior to measurements. As already recognized (Egenhofer and Mark 1995), there is a big gap between what a human user wants to do with a GIS and the spatial concepts offered by the GIS. The space syntax approach introduced here yields an alternative to spatial apprehension, and it can be employed to make predictions of human behavior. By implementing an extension of space syntax approach, we have successfully brought the approach to GIS users for morphological analysis (Jiang 1998).

Space syntax has proved to be a substantial model for urban studies, but it is not without problem. Amongst others, the following two points are critical. Firstly, the notion of axial lines is quite fuzzy, although we attempt to regard it as the representation of vista space in this paper. Secondly, the generation of axial maps for an urban system is still manual, and there is no efficient automatic way to do it. Although there are some principles to draw axial lines, it is hard to guarantee the consistency of axial maps. For instance, the claim (Hillier and Hanson 1984) that an axial map is the least set of longest axial lines is not proven.

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Here I provide two abstracts of recent and current research that provide a sample of some of the perspectives that I'll share in our workshop. These abstracts represent just a small sampling of my research perspective – that in general attempts to merge semiotic and cognitive approaches to understanding spatial (geographic) representations and human use of concrete spatial representations to prompt and modify their cognitive representations of space. A much more detailed explication of this representational perspective can be found in *How Maps Work: Representation, Visualization, and Design*, Guilford Press, 1995.

Abstract 1: This abstract summarizes a limited experimental project that I am working on with two graduate students. It is part of a larger NSF-funded effort in which I play a minor role, Visualizing Earth [http://visearth.ucsd.edu/]– the focus of which is research in cognition and perception to better understand the developmental process students go through as they learn to use visual georeferenced images and tools, and how visualization tools can help students progress more rapidly and effectively in learning about earth sciences.

Exploratory Data Analysis and map animation: Using temporal brushing and focusing to facilitate learning about global weather

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LINEAR AND CYCLIC TEMPORAL LEGENDS: ASSESSING THE IMPACT OF LEGEND DESIGN IN GEOGRAPHIC VISUALIZATION

Abstract: Understanding processes of the earth system demands a sophisticated comprehension of the temporal as well as spatial aspects of those processes; air temperature, for example, contains diurnal, weekly, seasonal, and inter-annual patterns which are played out differentially across the surface of the earth. Trying to understand the relationship between multiple climate variables

complicates this task further. Representing such a complex spatio-temporal relationship is a significant design challenge. We report here on the second stage of a project directed toward developing a set of space-time visualization tools designed to facilitate earth science learning. Our research has two primary goals. The first is to integrate two exploratory data analysis methods (brushing and focusing) with map animation to produce a manipulable dynamic representation that facilitates a conceptualization of time as both linear and cyclic. The second goal is to explore the use of these tools in a Geographic Visualization (GVis) system which allows students to conceptualize the spatial and temporal aspects of multivariate continuously changing phenomena (specifically weather and climate) and to develop hypotheses about those processes. To meet these goals, we have built the GlobalWeatherAnalyzer (GWA) that facilitates examination of three aspects of global weather (land temperature, ocean temperature, and cloud cover) as they relate to one another in both time and space. Stage one of this project involved building and assessing a prototype of the GlobalWeatherAnalyzer. Assessment was carried out using a focus group methodology. In the second stage of this research, reported here, we assess the impact of different temporal legend styles (i.e. cyclic, linear) on the user's problem conceptualization -- and thus on their ability to develop an understanding of earth-climate processes. Rather than focusing on performance differences resulting from the use of different temporal legend styles, our interests lie in determining whether these tools prompt different knowledge schemata, stimulate different approaches to problem solving, and ultimately, if they lead to generation of different hypotheses about the relationship between two climate variables over both space and time. Legends in a dynamic learning environment serve a dual role, as a key to the "sign-vehicles" embedded in the display (i.e. to the symbols used to represent phenomena) and as a control on parameters of those sign-vehicles (as what is often called an "interactor"). In the research reported here, we specifically investigate the impact on problem conceptualization (i.e. on the knowledge schemata brought to bare on the problem), of providing two temporal legends-interactors that represent and provide control over linear and cyclic views of time. Participants in our study (students at Penn State University) are given the task of describing the space-time characteristics of two climate variables depicted on a dynamic map and then generating hypotheses about the relationships, over time, of these two variables. How participants use the GWA to explore data while developing these descriptions and hypotheses is recorded. Analysis of the descriptions and hypotheses generated is used to characterize participant's problem conceptualization. Comparison of descriptions and hypotheses to patterns of system use allows us to characterize the impact of each legend as both a key and a control.

Abstract 2: This abstract of a paper to be presented at the spring AAG meeting highlights a new project directed toward use of virtual environment tools for visualization of georeferenced information and for study of spatial cognition. This abstract emphasizes the former, but we expect to extend the work to address a variety of cognitive issues.

Exploring the Potential of Immersive Virtual Environments for Geographic Visualization

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As georeferenced data volumes continue to expand, scientific analysis and policy decision making based upon these data become increasingly complex. Advances in computer graphics technologies offer new methods for dealing with that complexity. Our focus here is on the potential for integrating geographic visualization (GVis) methods with technologies for immersive virtual reality, for application to environmental science and policy decision making. We propose a categorization of visualization environments that emphasizes the extent to which these environments share characteristics with real environments. This categorization is then matched with four categories of visualization task (exploration, analysis, synthesis, and presentation) and the advantages, disadvantages, and key unanswered research questions related to each combination are noted. We then present a case study in which we have applied both non-immersive and immersive dynamic three-dimensional visualization tools to exploration and analysis of spatiotemporal climate data. The immersive tool we are working with is an ImmersaDesk from Pyramid Systems. Among the issues to be considered as we compare use of the two environments are: (1) applicability of each display form to visualization problems in which representation is spatially iconic (i.e., geographic space is mapped to display space) through increasingly abstract representations (i.e., with display dimensions all used for non-geographic data dimensions); (2) differences in interface control styles necessary for effective interaction in the display environments, and (3) relative potential for collaboration among individuals (locally and remotely). *supported by: U.S. Environmental Protection Agency & Penn State Center for Academic Computing* Keywords: geographic visualization, virtual reality, environmental analysis

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In the heart of Silicon Valley, visitors to the Mountain View Public Library may find their way to various places within the library by viewing an animation depicting the route to the desired location. The Silicon Graphics workstation in the entryway of the library shows the library's floor plans. After choosing where in the library to go, an animated dotted line on the floor plan shows the visitor how to proceed there. Although this is a technically literate part of the country, the librarian reports that visitors do not like, and do not use, the animated location finder. They prefer instead to ask the librarian for directions or to use a printed paper map to find their way about the library.

The use of computer animation in everyday situations is becoming more popular and the use of animation in instructional settings has become exceedingly common. Matt Lauer, on a recent *Today Show*, interviewed James Oppenheim, the technology editor of the Oppenheim Toy Portfolio. Oppenheim reviewed and recommended different educational software programs aimed at children from preschool through high school. Each program displayed on the show integrated computer animation into the software. Additionally, *Newsweek* magazine recently published an article comparing the ease with which someone could learn to play the guitar from a CD-ROM tutorial with learning from a live tutor. With a computer tutorial students may proceed through the lesson at their own pace, but the computer can only provide a limited amount of feedback should the student run into difficulties. Overall, the reviewer concluded that the computer tutor could not compete with a live tutor. This conflict between wanting to use animation and not being assured of its effectiveness is the state in which current researchers of computer animation find themselves. People seem to like computer animation and believe it is a superior educational aid when compared with static or no graphics (e.g. Gurka & Citrin, 1996;. Despite these endorsements, researchers have had difficulty demonstrating conclusively that computer animation positively affects learning.

A demonstration of the general effectiveness of computer animation is not appropriate however. The question, "Is animation effective in facilitating student learning?", cannot be answered with a simple yes or no. There are numerous factors to consider when animation is used in an instructional setting. Animation, like textual information or illustrations, is an instructional tool, not an instructional solution. As with any tool, only appropriate use will result in the optimal outcome. However, with the current popularity of computer use and the ability to animate numerous types of information, instructors and software companies appear to be relying on intuitive notions that animation works rather than investigating its effectiveness before creating animated programs. They seem to think animation can be used indiscriminately and will achieve the desired effect of greater student learning. What needs to be clarified, however, are the conditions under which animation has the best chance of being successful and which provide the least chance.

Animation is an instructional tool, not an instructional solution. The simple process of animating information does not necessarily lead to a student's development of a conceptual understanding of the presented material. Although many animated programs are being used in instructional settings, the basis for their use has not been empirically established. However, researchers are working to define the circumstances under which animation facilitates learning in an effort to improve animation's use as an instructional tool.

After considering the many failures of animation to facilitate learning in algorithm animation situations, Gurka and Citrin wondered whether enough evidence could ever be amassed to convince researchers that their intuitive notion of the instructional effectiveness of animation was wrong. Although there have been successful demonstrations of animation's effectiveness in educational settings which should preclude researchers from giving up on the use of animation, the point Gurka and Citrin are making seems to be that people's intuitive sense of the effectiveness of animation will keep them continually researching and utilizing it. Hopefully, the research will come to precede animation's utilization. Regardless, what becomes most important is clarifying what conditions make animation effective so they can be exploited during its use.

The purpose of animation when used in an instructional setting is to serve as an aid to student learning. In order to achieve this purpose, students should be presented with the type of information that will help them develop a conceptual understanding of the material. In many cases, the conceptual understanding will take the form of a mental model which the student can use to make inferences about the informational domain and solve problems relating to the domain. Research into the effects of both illustrations and animation shows that these instructional devices can aid conceptual development (e.g. . However, additional research is needed to identify what other factors are important to the design of animated programs.

In some ways, the effects of animation on learning have been investigated for decades. Since animation can be regarded as a specific form of illustration, illustration research may provide insight into how to use animation optimally. Illustrations have been used as attentional and motivational devices. They appear to facilitate student learning when depicting the type of information essential to the establishment of a conceptual understanding of a domain. Since illustrations are a visual device, they may only facilitate learning when visualization of the information is necessary. In some cases, this visualization shows the workings of actual devices.

In other cases, illustrations are used to help the learner visualize the conceptual nature of the information and aid students' mental model formation. Although an illustration may fulfill the above requirements, it still may not be an effective learning device. Research has suggested that students may need to be schooled in illustration literacy; they may need to be taught how to attend to and interpret illustrations. Finally, differences in ability may affect students' use of illustrations.

In many ways, research on animation has shown that what affects learning from illustrations affects learning from animation. In most studies of illustrations, the illustrations are used as a supplement to textual information. Researchers of animated displays suggest that animated programs incorporate verbal information to allow the learner the greatest opportunity to develop an understanding of the information. As a result of the limitations of the working memory system, this verbal information is suggested to be auditory and concurrent with the animation. Research also provides evidence that neither illustrations nor animation will be particularly effective if the depicted information is easily imagined or unnecessary due to the skills of the learner. Since animation still is a relatively new medium, many people may not realize how to interpret it or use it for learning. Animation is a potentially more complex form of illustration and as such the necessity to teach people how to utilize it may be greater than the need to teach the interpretation of illustrations. In either case though, it appears as if students would benefit from instruction aimed at helping them extract the appropriate information from an illustration, animated or not. Finally, individual differences in ability seem to affect both learners using illustrations and those learning from animation.

Even if animation is a subset of illustration, there still are substantial differences between the two media and how each can be used. For this reason, research specifically on animation is crucial for truly understanding animation's effectiveness in instructional settings. Animation is defined by its ability to display motion and, consequently, may facilitate learning when the information to be learned is motion information. When the animated motion fails to add anything of substance to the display (e.g. when the only difference between an animated and a static condition is that the cursor moves between icons in the animation condition whereas the cursor just points to the icons in the static condition), there may be no facilitation effect. As an instructional device, animation may facilitate learning best when used as it was intended. In this case, this means using animation to depict information contained in the generated motion.

The other area where research on illustration cannot inform those who study animation is interactive or simulation animation. When students use an interactive animation, they actively manipulate variables and view the outcomes rather than passively observing the animation another has designed. While most research suggests that interactive animation positively affects students' learning, one problem arises when considering what comprises an interactive animation program. Interactive animation programs not only incorporate simple animation, but also include other instructional devices like verbal information as part of their structure. Furthermore, the importance of the students' interaction with the program cannot be underestimated. Students are actively involved in hypothesis testing when they repeatedly chose input variables and run the animation to see the different outcomes. These additions to the simple use of animation makes it difficult to determine whether animation facilitates learning or whether similar interaction with the material outside an animated setting would affect learning as much. Although this aspect of animation needs to be investigated, it does appear that when animation is used in interactive situations there is a good chance that students' understanding of the information will be facilitated.

Robert Abel, in a review of the history of computer animation, is quoted as saying, "I think [computer animation is] going to become a standard tool of expression in the same way alphabets became, or hieroglyphics". Considering the popularity of animation and how often it is used, in educational software, in product demonstrations, on the World Wide Web, one cannot help but think that animation's use will only expand in the future. It may be that animation will become a standard medium for communication. However, if it is going to be used effectively in instructional settings, designers of animated programs must consider under which conditions animation appears to facilitate learning and how these factors interact with one another. Even more important to the future use of animation will be the research continually exploring animation's impact on instruction. What is most critical to remember, though, is that animation is what Able said, a tool, and one to be used cautiously and wisely.

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Position statement: Geographic knowledge as a multi-representational and dynamic system

Our World View as a Cognitive Map

The most frequently used metaphor for describing the form of our geographic knowledge is the *Cognitive Map*. This term within the context of human cognition usually refers to the cognitive representation of geographical-scale space, and includes the immediate space of one's own neighborhood as well as very large and complex spatial entities such as towns, cities and whole environments. Because of their size, such entities cannot normally be seen in their entirety. It is the total collection of these mental maps, each representing a specific domain (my home town, the way to work, known countries of the world, etc.), that together comprise our World View. The idea of a cognitive map is a convenient and obvious metaphor for the representation of geographic space. The map as a graphic product is, after all, one of the most familiar means of storing and communicating knowledge about geographic space. As such, the metaphor of the cognitive map has been often used without further elaboration or explanation. There are implications of this metaphor that can be very misleading with regard to conceptual structure, and care must be taken to avoid more than the very broadest of interpretations.

The mental map metaphor conjures-up the notion of some unified representation as a graphic artifact inside each individual's head that contains the sum-total of that individual's geographic knowledge - that the cognitive representation of geographic knowledge is isomorphic with the graphical map and that we retrieve information by reading this "master map" with "the mind's eye." Certainly, our knowledge is highly interrelated, like the graphic map. Nevertheless, most known aspects of our cognitive representation of geographic space do not fit the mental map metaphor.

Examining the characteristics of a graphical map display relative to cognitive structure can nevertheless be illuminating with regard to the characteristics of the mental representation of geographic space. It seems intuitive that we do not literally store geographic knowledge as maps; using cartographic symbology, with dashed lines for dirt roads, etc. Most of our geographic knowledge, is not actually stored in any sort of graphic form, cartographic or otherwise. Even though we often talk about "mental imagery", mental images are also not exact copies of reality, analogous to a photograph. They are perhaps best described as image representations that have been possibly, but not necessarily, derived from some visual stimulus. Most adults are familiar with imagery conjured-up from reading a novel or a poem, or by listening to music. According to Piagetian development theory, there are image-like representations early-on in learning, but that they also play an increasingly subordinate role as the active component of memory as thought processes mature and become capable of abstract, logico-mathematical operations and knowledge becomes better organized.

A number of researchers have asserted that knowledge is encoded as a combination of image and non-image forms including pictorial, schematic, mathematical, textual, and auditory (Anderson 1978; Ioerger 1994; Hayward and Tarr 1995). But - doesn't this get us back to the metaphor problem again? Do we really have knowledge, particularly most of our "abstract" or "higher-level" knowledge encoded into words, mathematical equations or even (graphic?!) schematic diagrams? Just on the basis of intuition, perhaps with a little introspection, this doesn't ring true. Downs has asserted that knowledge within the mind has no form at all - that it is pure relation (Downs 1985). In his view, knowledge takes on an explicit form only for the purposes of communication; to convey information and/or facts to another. This is by definition external (as opposed to internal) knowledge representation. External representation can take many forms, including words, images, diagrams and maps. We must therefore maintain a careful and conscious distinction between external and internal forms. In (externally) describing the form of internal knowledge, using the normal, external forms we use to communicate seems almost automatic, whether or not they are really appropriate.

It is undeniable that we can indeed conjure-up visual imagery in our minds, which may be the result of a remembered visual experience or a mental creation of; a real-world scene, a drawing or a map. We have similar "imagery" with respect to specific words and mathematical equations - even music. All of these can be recalled as sensory sensations, whether they are completely imagined or based upon actual sensory experience. From the Piagetian perspective, sensory sensation is the beginning of learning. We also recall that the first type of knowledge within this framework is variously called figurative, declarative or (on a geographic scale) landmark knowledge. This consists of what might be termed experiential or observational knowledge - i.e., stored sensory sensation and is not abstract or derived knowledge. On this basis it would seem reasonable to say that such knowledge could be cognitively encoded as stored sensory sensations - which indeed could include a visual recollection of words on a printed page. Can we say that all *other* types of knowledge, i.e., the more "abstract" or "higher-level" knowledge is pure relation, as Downs has suggested? We have already discussed learning as a process of grouping and abstracting. Wouldn't this at least include the modification of remembered sensory sensations over time to fit accumulating knowledge and evolving points-of-view (in addition to simple forgetting)? Another argument potentially supporting the idea that at least some "abstract" or "higher-level" knowledge is encoded into visual, auditory or other external forms is again the argument that such external forms can and do channel how we think.

Tulving (1972) made a distinction between episodic and semantic. He described episodic memory as the kind of memory that receives and stores information about specific events and groups of events (i.e., episodes), and the space-time relationships among those events. This is the type of memory that deals with remembered experience. Semantic memory is the organized knowledge a person possesses about concepts and their interrelationships. Unlike episodic memory, semantic memory does not refer to unique episodes or events, but rather to universal principles. Information in episodic memory is recorded directly from perception and is susceptible to forgetting. Semantic memory, although it can be recorded directly (by, say, reading a textbook), is often derived through a combination of perception and thought. Through the learning process, certain events and episodes become associated with concepts in semantic memory as examples. It therefore seems reasonable to view our cognitive representation of geographic space as both semantic and episodic. Reading or talking about a neighborhood in our home town, or about some other familiar city may prompt visual memories of a restaurant we visited there, etc. Thus, events and episodes are remembered as sensory sensations, and are also a component of "higher-level" knowledge.

Another problematic aspect of the cognitive map metaphor is that it easily leads to the implicit assumption that the cognitive structure of our spatial knowledge is dynamic only in the sense of its original construction and subsequent modification as we learn. Nevertheless, there is a significant amount of empirical evidence showing that we have multiple cognitive representations for the same geographic environment (Kuipers 1978; Garling, Book et al. 1984; Bryant, Tversky et al. 1992; Franklin 1992.) Not only can we have representations in point-oriented, linear or survey form for a given domain because of our level of knowledge, our representation for knowledge belonging to the same domain changes depending upon the task at hand. Thus, people have a route-oriented representation for the path they drive to and from work every day and may generate a route-oriented representation when driving around a familiar city or when asked to give directions. As a specific experimental example, Taylor & Tversky have shown that people who read about an extended environment from either a route-perspective description or a survey-perspective description could answer questions utilizing apparently flexible perspectives. The perspective used in the text for the original learning task did not seem to affect the ability to answer such questions (Taylor and Tversky 1992). This gives further support to the notion that our brains structure representations on-the-fly.

In contrast to the properties of a map as a graphical artifact, then, the structure of our knowledge representation is not static and monolithic, but is dynamic and multifaceted (Montello 1992). Our cognitive spatial representation can be discontinuous or linear (route-oriented), segmented, and incomplete. Accommodation of these properties has lead Barbara Tversky (1993) to describe our World View as a cognitive collage rather than a cognitive map. This, however, derives from the map metaphor and retains some of the same problems, such as the lack of reflecting the dynamic nature of our cognitive spatial representation. Perhaps a better way to describe it is as another multi-stable system. As such, the various representational forms of the environment are not stored in any static fashion. Representations are dynamically generated, depending upon the initializing circumstances and can be in any of a number of forms and modes (visual, verbal, etc.).

How is spatial knowledge encoded?

What, then, can be said about the primary components of cognitive spatial representation? Certainly, the distinction between the external world and our internal view of it is key, and it is helpful to explore the relationship between the two further from a process-oriented perspective.

The classical approach assumes a complex intern al representation in the mind that is constructed through a series of specific perceived stimuli, and that these stimuli generate specific internal responses. Research dealing specifically with geographic-scale space has worked from the perspective that the macro-scale physical environment is extremely complex and essentially beyond the control of the individual. This research, such as that of Lynch and of Golledge and his colleagues, has shown that there is a complex of behavioral responses generated from correspondingly complex external stimuli, which are themselves interrelated. Moreover, the results of this research offers a view of our geographic knowledge as a highly interrelated external/internal system. Using landmarks encountered within the external landscape as navigational cues is the clearest example of this interrelationship.

Portugali (1996) has recently extended this view and explicitly acknowledged a complex interrelationship between our internal representation and the external environment. Furthermore, he asserts that elements in the external environment act as an interrelated knowledge representation, external to ourselves, that functions in concert with our internal knowledge representation.

The rationale is as follows: We gain information about our external environment from different kinds of perceptual experience; by navigating through and interacting directly with geographic space as well as by reading maps, through language, photographs and other communication media. With all of these different types of experience, we encounter elements within the external world that act at symbols. These symbols, whether a landmark within the real landscape, a word or phrase, a line on a map, or a building in a photograph, trigger our internal knowledge representation and generate appropriate responses. In other words, elements that we encounter within our environment act as knowledge stores *external* to ourselves.

Each external symbol has meaning that is acquired through the sum of the individual perceiver's previous experience. That meaning is imparted by both the specific cultural context of that individual and by the specific meaning intended by the generator of that symbol. Of course, there are many elements within the natural environment not "generated" by anyone, but that nevertheless are imparted with very powerful meaning by cultures (e.g., the sun, moon and stars). Manmade elements within the environment, including elements such as buildings, are often specifically designed to act as symbols as at least part of their function. The sheer size of downtown office buildings, the pillars of a bank facade and church spires pointing skyward are designed to evoke an impression of power, stability or holiness, respectively.

These external symbols are themselves interrelated, and specific groupings of symbols may constitute self-contained external models of geographic space. Maps and landscape photographs are certainly clear examples of this. Elements of differing form (e.g., maps and text) can also be interrelated. These various external models of geographic space correspond to external memory.

From the perspective just described, the sum total of any individual's knowledge is contained in a multiplicity of internal and external representations that function as a single, interactive whole. The representation as a whole can therefore be characterized as a synergistic, self-organizing and highly dynamic network.

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Leonardo Article
Virtual Space and the Construction of Memory

Abstract:
In this article, the author presents the theoretical perspective behind her art work. She describes influences, background, and production of four interactive installations and three performance works using computer multimedia, electronics, and/or robotics. The work's inspiration is contemporary theories related to the structure of the human memory. It explores conceptually the relationship between physical space and the virtual space of the mind. It uses the computer as a tool, but also as a raw material with social implications. Early work employed theories of short term memory (STM). Later work was based on long term memory (LTM) concepts such as episodic and semantic memory. Current explorations place the viewer in motion or implied motion and refer to continuity or lack of continuity in conscious thought.

Note: The definition of virtual as used in this article is something, which is simulated, which exists as image rather than physical reality. According to this definition, the mind is a virtual brain. It exists conceptually, but the actual physical matter is the brain.

Introduction

The development of my work has been focused on the relationship between physical space and the virtual space of memory and the mind. Interactive computer applications in the work metaphorically imply internalized information and physical space emphasizes the physical aspects of cognitive activity. Early work, the Appetite and Fetish series, used physical objects as the embodiment of specific memories. The work then moved conceptually to using a specific location as a container for history and memory, as in the Observatory. Current explorations place the viewer in motion or implied motion to refer to continuity or lack of continuity in conscious thought. I see motion as similar to the experience of consciousness. The moment acts as a glimpse of timelessness, an impression that can never be examined through the linear progression of time.

Composition and Chaos

Our sense of time seems to be constructed from landmark events in the environment, which act as clocks, and from which we get our temporal bearings. In this sense, the whole world can be viewed as an ensemble of clocks, which we use at various times for various purposes. [1]

The mathematics of chaos fascinated me ever since James Gleick's Chaos: Making a New Science [2]. I was interested in the ability of the computer to discover new geometric structures by performing large amounts of calculations. In the case of chaotic systems, naturalistic forms were created through iterative formulae. As a visual artist, this was interesting to me because it created a link between abstract mathematics and naturalistic forms.

In 1989, as an MFA candidate at The Art Institute of Chicago, I was fortunate to work with George Lewis, a jazz trombonist and pioneer in human/computer musical improvisation. He counseled me in the creation of Chaotic Systems in Musical Improvisation. This project, programmed in IRCAM's Max software, was a system of improvisation for musician and computer based on the Lorenz attractor (image 1).

A lorenz system is described by the solution of three simultaneous differential equations:

dx/dt=3D-ax+ay
dy/dt=3D-xz+rx-y
dx/dt=3Dxy-bz

In Chaotic Systems in Musical Improvisation, the lorenz attractor took an initial value input from a midi keyboard and generated a series of X and Y coordinates. These values were used on a macro scale as time and duration values. That is, the program captured chunks of numerical data (midi information) in real time based on the notes played by a musician. The size of these 'chunks' and when they were captured was determined by the lorenz attractor algorithm. The system would then play back these chunks in time using the same algorithm.

The resulting improvisation, which for performer and listener felt very much like an improvisation between two human musicians in performance, was inspired by Robert R. Snyder's work on memory in musical perception. In his book, Music and Memory: A Brief Introduction [4], cognitive concepts are used to analyze musical structure. Short term memory (STM) including chunking and long term memory (LTM), including non declarative, declarative, episodic, and semantic memory are discussed at length in relationship to musical concepts such as rhythm and meter.

Snyder's analysis of musical structure based on short term memory (STM) is the basis of the design of Chaotic Systems in Musical Improvisation. Short term memory is the second stage in the memory chain; a temporary memory which holds its contents for 3-12 seconds and has a limited capacity (5-9 items). This area of memory is the location of awareness of the present. In my system, groups of notes played by the live performer were selected using duration values within the limits of STM generated by the attractor, as were durations of delays (pauses) between these groups. What was unexpected and especially interesting about the system in performance was that the live performer was able to use his/her STM to anticipate and manipulate the reactions of the system. I believe that this predictability was possible because the Lorenz attractor was used to generate values. The attractor established a waxing and waning pattern that a live musician could anticipate and respond to.

Storage/Retrieval

I raised my lips to the teaspoonful of the tea in which I had soaked a morsel of the cake. No sooner had the warm liquid and the crumbs with it, touched my palate than a shudder ran through me. [17]

White Wall/Black Hole led to another installation piece dealing more directly with desire in the virtual and physical world. This piece was my first installation work to exist in both physical and virtual space. The piece was installed in the summer of 1995 at Here, in New York City. The Appetite exhibition, conceived of and curated by Michael Casselli, who had been working with the idea of the human appetite for several years, included the installation work of six artists. The overall exhibit was designed by Casselli to echo a garden, complete with garden lighting and smells.

Research into the concept of the appetite led me to consider my personal appetite for possessions. It became clear that I along with many others have multiple layers of possessions. We have possessions in physical space, and we have possessions in virtual space: images, sounds, and texts in analog and digital media. My work specifically consisted of 32 porcelain dinner plates suspended on the walls of a small space containing actual materials symbolic of my personal desires. (image 5) A cellular phone, for example, referred to protection, i.e. the idea of being untouchable; keys referred to power and control . Each material on the plates was photographed in its "ideal" state, lit like a commercial product. (image 6) Objects of desire in the virtual world exist in a visually heightened state to compensate for the lack of physical touch. Remote visitors could access the desires in the virtual world through the world wide web.

Another manifestation of this work was created for the Nylistafnid Museum in Reykjavik, Iceland as a part of the Altitudes/Attitudes exchange show sponsored by Nylistafnid and Artemisia Gallery. In this version, I selected only twelve plates of clear glass rather than porcelain. The materials on the plates were the more ephemeral: air, sound, magnetic energy, etc. One of the plates, filled with wine, was placed above a large speaker which emitted the sound of a heart beat. With each beat, the surface of the wine would distort to a series of circular ripples. Light, bounced of that plate and on to the wall, created a pattern of motion that was reproduced on the wall. (image 7) This work dealt with longing and loss, using ephemeral material as a direct reference to an emotional state. The wine and heartbeat referred to the physical body's experience of emotion.

One explanation is that throughout one's lifetime, experiences with common objects are stored in permanent memory--not as singular instances, but as items organized around a central theme...We recognize and classify a variety of disparate objects (cups and saucers) as members of a class by rapidly comparing them with an "idealized" image of the class...It is the idealized image, or prototype, of an object, person, feeling, or idea that is stored in our long-term memory. [18]

The human mind..operates by association...in accordance with some intricate web of trails carried by the cells of the brain [19]

The idea of possessions in virtual space explored in Appetite led me to the conscious realization that virtual possessions are actually an integral part of non-digital life. Every human being has a storage bank of virtual possessions, memories. In fact, the computer storage bank is understood in human terms only through the metaphor of the memory.

Fetish, a part of Command-Shift-Ctrl in May of 1996 at NAME Gallery in Chicago explored the issue of memory in virtual and physical space. The installation consisted of twelve objects suspended over the heads of the viewers on a glass drop ceiling. A computer in the space provided a virtual replication of the objects. In positioning the objects, I was attempting to create a body metaphor for the action of remembering. There are physical correlates to many emotional states. For example: joy is experienced as a physical buoyance, and in contrast, grief is experienced as physical weight. When trying to remember, often humans will move their eyes up and to the side. (image 8)

Each object was lit with a dramatic spotlight which created an exaggerated shadow of each object on the walls of the space. Like in Appetite, lighting served to give the objects a "larger than life" presence in the space. I wanted to create a physical space that might refer to the virtual space in the mind when remembering events and objects. Certain events have prominence in the mind, and the physical metaphor of size/importance is referred to in the space using oversized shadows, which are foggy reproductions of the actual event/object.

The objects were selected as signifiers of personal experiences related to relationships I have experienced. Viewers could access the computer using an interface sensitive to touch. A visitor could select each object to obtain a personal story related to the memory of the object and a sound which was used as a signifier of the emotional quality of the story. The stories were selected for their prominence in my personal database of memories, and described in a way that left the reference to the object somewhat ambiguous, and/or cross-referenced to more than one object. (image 9) This structure referred to the fluid nature of the experience of a memory. One memory leads to another in unpredictable ways.

The sounds on the system, like smells created by Casselli in Appetite, were an effective means to evoke memories in the viewers. They were chosen for their familiarity: a door knock, a car door slamming, birds calling, ice clinking in a glass, etc.

Like Appetite, this work was also re-worked for other spaces. At the University of Indianapolis in November of 1996, Fetish was created by using 100 2X2 cardboard boxes. The boxes were stacked to the 40 ceiling of the gallery. The boxes were used to create an environment of a warehouse or storage space, and at the same time creating an atmosphere of mystery as the contents of the boxes were not revealed. On the surface of one of the boxes, a video was projected of the series of idealized objects.

Since beginning this project, there has been a fluid exchange of objects in each work. Objects gain and lose importance in my personal memory, and that is reflected in the objects evident in each work. I suppose I am trying to re-create my state of mind at a given moment in time.

Fetish, May I Help You was a collaborative version of Fetish created in January of 1997 with students of Alfred University. (image 10) The students collected their personal fetish objects: some found and some made and wrote short stories related to the objects and desires. These objects were then photographed and placed with the stories on an interactive CD-Rom. The objects were displayed in glass cases on the first floor of a storefront space in the town of Alfred. On the second floor, a dark 'cabaret' atmosphere was created with a projection of the interactive application and live performance. Visitors were invited to enter a tiny 'confessional' and record their private fetishes on video tape which was then broadcast onto the street of the town.

In November of 1996, I further explored this idea in a collaborative performance with artists Jan Erik Andersson, Louise McKissick, and Jeff Callen. We met as a group and discussed our work and interests. Andersson, who was on a residency from his home in Finland, discussed the discomfort he felt as a child in his father's absence. This sparked a group discussion of each group member's father and led to a performance, P-P-Pa-Pa, which used a fractured narrative of stories, past and present, and video projection into a pool of water in which viewers could direct a small remote-controlled boat. The performance was a metaphor for the process of trying to remember that which one could not understand.

Interior/Exterior

Here, everything is a "predicate of existence": no dialectic but the terrible simultaneity of "white walls/black holes"; a matter of "synthetic apperception" taking the materialist form of the three syntheses of Anti-Oedipus: the "connective synthesis of production" (understanding), the "disjunctive synthesis of recording" (imagination), and the "conjunctive synthesis of consumption-consummation (reason). [5]

White Wall/Black Hole, shown in January of 1993 at Artemisia Gallery, was one of the first pieces created to address communications media in gallery installation rather than performance. The piece consisted of a flour-coated gallery wall shaken by live sound from the area outside the gallery using a police radio scanner. The flour on the wall slowly fell to the floor of the space due to the vibrations of the sound. The flour-coated wall visually referred to a topographical map, changing slightly with each new bit of audio information. (image 4) In the creation of this work, I wanted to address information accessible to individuals through technology. Like the Stein/Doorika piece, this work addressed desires awakened by access to technology. The desire for power and the acquisition of power through information was contrasted with the content of the messages, live police radio dispatches.

Police radio in the piece acted on two forms of the listener's memory. On the one hand, the comprehension of speech is the basis of acoustic memory. Comprehension of the text depended on the listener's short term phonological memory which serves as an 'articulatory loop' which helps preserve order and allows the listener time to process continuous streams of speech. The listener's long term semantic memory was also engaged, that part of the mind which contains schemas, or generalizations about world order.

The title of the work was a reference to 1,000 Plateaus, by Gilles Deleuze [14]. BlackHole/White Wall is a reference to the Baroque and nature. It refers structurally to the union of opposites.

The monad is the autonomy of the inside, and inside without an outside. It has as its correlative the independence of the facade, and outside without an inside. [15]

The Baroque is inseparable from a new regime of light and color. To begin, we can consider light and shadows as 1 and 0, as the two levels of the world separated by a thin line of waters.[16]

The paradox of Deleuzian theory being addressed in this piece has to do with the concept of opposition, the idea of two halves, an inside and an outside, and, as a sculpture, space and non-space.

...their past, their culture, their native places, their families and friends; an attachment which they carry with them all their lives, regardless of where destiny may fling them. Andrey Tarkovsky [20]

A particular place can be seen as an energy, a presence, the essence of a locale, a force which evokes an emotional response. I have moved from working positioning objects in space to exploration of the space itself: geographic and architectural position.

The Observatory, organized by the artist's group SEL, Super-on ExLibris: Tomas Geciaskas, Sigitas Lukauskas, Rasa Staniuniene, and Sigitas Staniunas, was an international site specific project which took place in the last weeks of April, 1997 in Vilnius, Lithuania. It included installation, performance, and theatre created by individual artists and in collaboration. [21] Seven Chicago artists participated: Donald McGhee, David Brown, Matthew Wilson, Steve Barsotti, Louise McKissick, Jeff Callen, and myself.

The observatory, established in the center of Vilnius by Tomas Zebrauskas in 1753, is one of the oldest observatories in Europe. In 1876, the western tower of the observatory burned, and in 1883 the observatory was closed, inaccessible, and almost forgotten until 1997. The Observatory is metaphoric, an interface created as a means to understand the world on a global scale. Through international collaboration: dialogue, interaction, and contextualization the participants in this project engaged in a similar process of global understanding.

My interest in The Observatory project is related to the metaphor of the historical function of the observatory related to the present explosion of information in the digital age. In trying to understand the implications of this drastic social and cultural upheaval, I looked to the time of the Enlightenment, when the operation of the observatory was at its height. During the 18th century, the observatory was an international center of scientific research with significant discoveries in the orbit of Mercury and the nature of light itself. In the present day, technology (this time information technology via email and web correspondence between artists and organizers) has made the observatory once again internationally significant.

In The Twins, through the use of robotics, light, interactive computer technology, and human interaction, I designed a system in which a structured set of rules created a complex and unpredictable event. (image 11) Complex patterns in black chalk were created by two performers controlling line-tracker robots. The cylindrical tower space served symbolically as interior mind space; and in this performance, the chalk marks left as a record of an event could be seen as a map of the mind.

In collaboration, performances were created in the space. Steve Barsotti used his skills as an instrument maker and musician to fashion instruments out of material he found in the observatory. The music of these instruments was then performed within the space itself. A remnant of Spinduline Spinae, a collaborative performance work by McKissick and myself, was hung out of the tower in which housed The Twins. (image 12) Spinduline Spyna (Radiation Lock in Lithuanian) consisted of one blindfolded performer in the tower reciting a series of significant dates in Lithuanian history, one for each of a long line of scarves as she let the scarves out the window of the space.

Motion and Perception

What we call reality--"this is it"; "I am here"; "this is happening to me" --is a certain relationship between memories and sensations that surround us at the same time. That is the only true relationship that marks the distinction between self and not-self. 'I' am the bridge between past and present, and also between present and future. This linkage demands something more than memory [22]

The experience of timelessness is similar to what George P. Landow calls the Borgesian Aleph.[23] That is, a point that contains all other points. Landow is referring to digital experience on the internet rather than physical experience: the idea that you can seemingly reach any point on the web from any other point. Is there an analogous position in the physical world? We consider time as linear, each point in time leading to another in succession. Yet, many claim to have experienced moments in time that seem to have a position outside that linear progression.

In the Siggraph '97 panel discussion moderated by Eric Paulos of the University of California, Berkeley entitled "Interfacing Reality: Emerging Trends Between Humans and Machines," performance artist Stelarc discussed the relationship between body motion and memory. She stated that when a person walking wants to recall something, the walking pace slows down. When someone wants to forget something, they naturally speed up their pace. Theoretical physics also expresses a relationship between time and motion, for example: the slowing down of time in travel at the speed of light. [24]

My current exploration is the expansion of location to motion. New work deals with the perception of continuity in conscious thought. I am attempting to change viewers' physical body perception and alter their expectations of control through inconsistencies in control and response in interactive installation.

Tight, shown in June at Artemisia Gallery, was a collaborative work between myself, McKissick, and Barbara Droth. (image 13) An interactive computer application [25] was displayed through an antique stereoscope. Sound, stories, and images could be accessed through a standard mouse interface, but the way the images were seen created a false sense of perspective. The application used stereoscopic 3D modeled objects as well as 2D graphics and video. The text was from an actual conversation with a stranger, a moment stored in my personal memory.

The performance aspect of the exhibition consisted of two performers in black wetsuits suspended from the ceiling of the gallery in climbing harnesses. Visitors to the gallery were then invited to suspend themselves as well. This process was my first experimentation in combining altered physical sensation with interactive media, this has recently been expanded to performance events controlled by subtle eye movements.

My most recent project, Gape, was created using a simple eye tracking device designed by An Reich. The device, which determines the position of dark or light pixels, uses input through a video capture card to control an interactive application. Gape was shown at Columbia College Chicago in Cache, an exhibition of digital work shown in conjunction with ISEA98 curated by Niki Nolin. In this piece, which was also performed at Artemisia Gallery, a live performer uses the eye tracking device as a mode of communication. A grid of nine regions on a 640X480 screen output the sound of eight words from the text used in Tight (one of the nine regions was inactive and used to create the effect of a pause or breath in the spoken words). The performer worked with the device and several sound processors to create a sound composition. At first, the viewer believed that the performer was trying to speak a complete sentence but was unable to control her eye movements enough to tame the sensitive technological device, but then the viewer began to listen to the soundscape created by the overlapping words and to appreciate the complexity of the combination and repetition. The eight words: I (You) (don't) want to be young (old), in combination created conflicting statements about the human body while the viewer watched a performer locked into an unmoving position, limited by the same technology she was controlling.

Conclusion

Art can be viewed as parallel to memory. Many of the same terms are used to describe the two. For example: art and memory both employ and integrate the senses, both are representations, and both refer to a sense of timelessness. Art can evoke memory and vice versa.

There are a number of metaphors in use today to help us understand how memory functions. I have concentrated on three major schemas in my work and used these schemas in the organization of this article: the spatial metaphor, the computer database metaphor, and the temporal metaphor. None of these schemas completely define memory with all its complex and inexplicable behavior. I have come to believe in the course of this research that at the present time that there are many aspects of memory that, like art, are not quantifiable.

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Research Abstract

The research abstract that I describe below falls into two parts. The first, philosophical, discusses the general nature of IRN and its implication to GIS, and the second, operational, shows how the abstract ideas can be cast into formal algorithms and simulation models. Some of the issues of this research abstract, (namely, sections 1, part of 2, and 6) have already been published, others will be presented here for the first time. The emphasis of my contribution to the Varenius initiative will be on the latter. The various bibliographical references made below can be found in Portugali (1996) and in Haken and Portugali (1996)

Part I: General discussion

1. A short remainder of IRN. This will be based on Portugali (1996). In this introduction the concept of IRN is constructed, first, by reference to its main inspirational sources, namely, Bohm's philosophy of *implicate* and *explicate* order, and Haken's *synergetic* approach to self-organization. Second, by reference to the writings of several cognitive scientists who implicitly or explicitly recognized the role of external representations within the overall process of cognition. I'm referring to people like Vygotsky, Gibson, Bartlet, Rumelhart et al., Johnson and Lakoff, Adelman, and others. Of the latter, Barttlet scenarios of serial reproduction are used as metaphors to convey and model processes of IRN.

2. Some empirical examples for its operation. The latter include, among others, (i) the Bartlett scenarios of serial reproduction, as devised by him in his study of *remembering*, (ii) *city-games*, which are public-collective serial reproductions that we have devised within the context of our IRN research. (iii) Golani et al. experiments with rats, which according to our interpretation show how the external and internal spaces are simultaneously constructed, and, (iv) several experiments we are currently conducting on emotional effects during navigation. The latter examine the hypothesis that externally represented body effects participate in the process of learning and navigation. These (and other) experiments illustrate the interplay between internal and external representations, and the self-organizing nature of the process.

3. On the relations between IRN and the foundations of cognitive mapping. In this section I show that the notion of IRN is already implicit in the elementary ideas of the founding fathers of cognitive mapping. On the one hand, in Tolman, who pioneered the concept cognitive map as an internal representation within the frame of externally represented behaviorism. On the other, in Lynch who, in his *The Image of the City*, has elevated the role of five elementary artifacts (paths, areas, junctions, nodes, landmarks) as legible external representations with which one builds the image (i.e. internal representation) of the city.

4. IRN and the computer metaphor. I'll show that the very Turing Machine, which is so central to the IPA and computationism, is essentially an IRN Machine. This claim is based on a new reading of Turing.

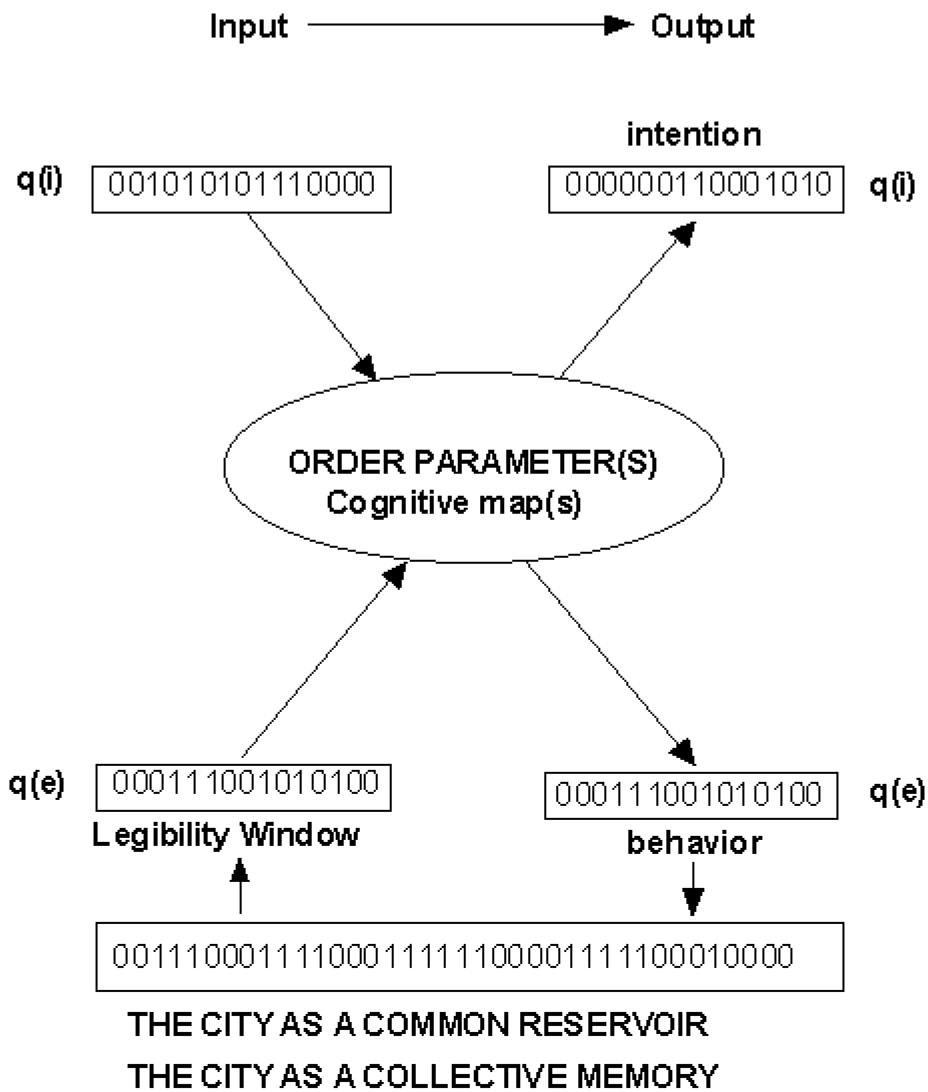
5. On the biological dimension of IRN. I'll show that the relations between internal and external representations that is central to IRN, typify also other biological systems. I'm refering to the relations between genotypes and phenotypes as presented by Dawkins in connection with his concepts *memes* and *extended phenotypes*.

Part II: Operational discussion

6. SIRN (synergetic inter-representation network). The first step toward operational implementation is the model SIRN developed by Haken and Portugali (1996). This model casts the notion of IRN into the formalism of synergetics – Haken's (1996) theory of self-organization. The building of SIRN starts with the so-called *synergetic computer* and adds to it externally represented inputs and outputs. The synergetic computer is a fully parallel computer, the neural network algorithm of which represents an alternative to the conventional neural network model.

7. The proper method of representation. Like all neural networks the structure of Haken's synergetic computer and consequently of our SIRN model, metaphorically mimics the neural structure of the brain. As long as one deals with internal representations only, this is indeed an advantage. However, when external representations are added as integral elements of the model, we are facing a problem. On the one hand, we have a neural net that enfolds information, while on the other, artifacts (buildings, cities computer systems, etc.) that enfold information. The challenge is to go beyond neural nets and artifacts and define a medium of representation that is appropriate for both.

8. The cultural code. The variable cultural code attempts to go beyond neural nets and artifacts and can thus be a medium of representation that is appropriate to both. It defines each individual cognitive system (each human individual) by means of internal and external representation, as in our SIRN model, and each representation, internal or external, by means of a cultural code, reminiscence of a genetic code. Technically, the cultural code can be defined by a Boolean vector. The theoretical foundation to this analogy between genetic and cultural codes is based on section 5 above. A graphical representation of this model is given below.



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Position Statement

The need for formalism

Formal models, using mathematical concepts, are applicable to the concerns of the workshop for a number of reasons. These models are important if we take a computer science viewpoint and consider the construction of GIS, which take account of cognitive models. As an example, take the issue of structure in cognitive maps. Hirtle (1995) considers hierarchical structures for spatial memory, and shows that the use of ordered trees or semi-lattices can be more appropriate than strictly hierarchical trees. If we want to implement GIS in a way consistent with a user's internal cognitive map, concepts such as ordered trees or semi-lattices can be used to structure the overall design of the system. Formal models are also relevant to thegeographical and the psychological viewpoints. The use of formalisms when building cognitive models of dynamic phenomena allows us to understand relationships between a variety of proposed models, and to assess the relative merits of different models.

Aspects of Change

There are several relatively recent developments in mathematics which can play a role in modelling cognitive aspects of change. Rather than attempt to catalogue everything which might be useful, I want to consider three topics. To understand how these topics relate to each other, and to the notion of change itself, I will first consider three aspects which are often present when dealing with phenomena of change.

The development of a city over an historical period provides a simple illustration. Concentrating on the region of space occupied by the city, we can isolate three aspects:

A domain over which change occurs (in this case time)

A property which varies (in this case the regional location)

An underlying entity which has continued identity throughout the changes(in this case the city).

It is important to realize that the domain of variation need not be time, but could equally well be space, or space-time, or something else. For instance, consider a GIS capable of displaying maps of a given region at various levels of detail. A user of such a system can think of what is provided as a single map (the underlying entity) which has an appearance which varies over a domain of levels of detail.

The three aspects identified are fundamental to modeling phenomena of change. Together they raise some important issues, which should be among those addressed by the workshop. Before elaborating on these specific issues, I want to consider a branch of mathematics, which has provided some significant insights into some of these issues.

Category Theory and its application to Cognition

The classical mathematical tools of set theory are well known and widely used in formal approaches to computer science, philosophy, cognitive science, artificial intelligence etc. These tools can be very effective, but have some serious limitations. For example, Smith (1995) concludes that *"Set-theoretic structure provides no basis for an understanding of the many and variedsorts of genuine unification (causal, biological, psychological, artifactual, institutional) by which the common-sense world is structured."*

Category theory provides an alternative approach to mathematics, which has much to offer those working in areas related to the topic of this workshop. A category in the mathematical sense is a particular algebraic structure, essentially a directed graph equipped with the ability to compose edges. The notion of category was formulated in 1945, and since then category theory has been used, among other things, as a way of organizing and understanding mathematics itself. It may well be that the success of category theory can be explained in terms of Lakoff and Nunez' (1997) metaphorical account of mathematics. One of the appealing aspects of category theory is its use of diagrams (originating from the underlying graphs). The use of arrows appears to exemplify Lakoff's *source-path-goal* schema, which is also important in the cartographic context (MacEachren 1995, p189).

There have been very few applications of category theory in a specifically GIS context, but there is clear evidence that further investigation would be worthwhile. Ehresmann & Vanbremeersch (1987) use category theory to model the emergence of properties within complex systems. Hoffman (1985) applies category theory to perceptual and cognitive systems. A particular way in which category theory may be important in modeling change is noted by Magnan & Reyes (1994, p58). They observe that the objects referred to in natural languages *"are ephemeral and changing, unlike numbers and sets which are timeless and constant. Category theory gives us the means to define a generalized (...) set as an object of a category satisfying some properties (a topos), without the temptation to go into over determinations..."*

Local and Global aspects of Variation over a Domain

In observing some changing geographical phenomenon over a period of time, how are individual observations over small time periods constructed into a model of the phenomenon over its entire lifetime? In learning a new environment, how do humans build up a global cognitive map from individual episodes of interaction with the environment? Both these questions have been the subjects of several studies, for an example of the latter one there is the combination of `local maps' and of `regional maps' in Chown, Kaplan & Kortenkamp (1995). The category-theoretic tools of sheaf theory are likely to helpful in providing a formal framework for dealing such questions, but their application to this area has not yet been explore din any detail.

Sheaf theory allows us to model `local' properties of structures, and their relationship to `global' properties. The notion of local versus global can be interpreted temporally (small portions of time within a larger interval), or spatially (small subregions within a larger region). It can also be understood in the context of variation over levels of detail. Sheaf theory has been applied (Sofronie-Stokkermans 1997) to modeling cooperating systems. One specific issue studied is how local plans, made by individual agents, can be combined to realize some global objective. It would be worth while to investigate whether the same mathematical concepts can applied to provide useful formal models in the GIS context, for example handling the combination of local (in any of the senses indicated above) observations into global ones. It appears possible that the Geocognostic framework (Edwards 1997) might be formalized as sheaves over a space of trajectories. Such an approach would be one way to investigate formal models of cognitive maps of changing environments.

Indistinguishability in Perceived Properties.

Arbitrarily fine distinctions are not possible in our perception of space. Even with the best conceivable instruments, there will point locations which we cannot distinguish, but of which we cannot be certain that they are distinct. This applies to any aspect of perception, for example colour, distance, sound etc. it applies just as much to spatial regions as to points. However, classical mathematical models of space fail to take account of this. We need to have a formal model in which we can say that entities P and Q are indistinguishable, and Q and $R$are indistinguishable, while allowing the possibility that P and R are distinguishable. Thus the relation of indistinguishability is radically different from equality as it need not be transitive. Thestudy of space in this sense was suggested by Poincare (1913), and was developed in more detail by Poston (1971), but much remains to be done. Varying the indistinguishably relation could be significant for understanding generalization in the context of dynamic visualization, which is acknowledged to be an important research topic (MacEachren et al. 1998).

Identity of the Underlying Entity

We speak of the same forest at two different times even when none of the trees remain the same, and when the physical boundaries are drastically altered. Similarly we think of cities as having continuous existence even though little besides the rough location of the settlement is identifiable as constant over a period of centuries. Yet mere preservation of location does not always mean that we would talk of *"the same city"*. The notion of continuation of identity is central the notion of change, yet has long been a source of philosophical problems (Gallois 1998). These problems are of practical relevance to any formal account of GIS technology, which is capable of dealing with change, and with how we customarily think and talk about change. One example where some of these ideas appear is in the change description language developed by Hornsby and Egenhofer (1997).

A significant approach to the semantics of identity has been proposed by Reyes, Macnamara and Reyes (1994). They develop a theory of reference applicable to certain linguistic entities, including proper names and count nouns. Some key elements of their treatment, including the notions of entity and of coincidence between members of different kinds, relies in an essential way on the tools provided by category theory. Their work is in a purely linguistic context, but offers considerable promise for application to entities in geographic space.

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Why I'd like to participate and what I've been working on that's related.

I've been interested in and done research in several topics related to those of the meeting:

Graphic displays: how they communicate, universals in how people construct them; how they are perceived and misperceived, remembered and misremembered; how they are interpreted; how to better design them.

Spatial cognition: distortions in cognitive maps; descriptions and depictions of the visuospatial world; geographic categories

More recently, my collaborators and I have become interested in the virtues as well as the difficulties of animated displays for conveying both concrete and abstract information.

Mireille Betrancourt (a former post-doctoral visitor from INRIA-Grenoble) and Julie B. Morrison (a current graduate student) and I have been conducting a literature search on attempts to improve learning or performance through animation. Mireille and I did a set of experiments using minimal animation, that is, successive presentation of organized (or random) elements of the whole. We found that successive presentation of organized parts lead to faster learning and to a relevant mental model as compared with random presentation. However, successive presentation was not superior to static whole presentation, in accordance with previous work on part-whole learning.

Our review of the literature has revealed that in many cases, animation does not improve outcomes. This has come as a surprise to many of the researchers, who fully expected animation to be beneficial. We developed an analysis of the failures of animation, attributing it to both perceptual and conceptual difficulties. This analysis suggests when and where animation may be successful. For example, the oft-said, represent space with space and time with time seems to be too simplistic. It is not the space or time itself that is critical, it is how space or time is conceptualized. The work of Hegarty and Zacks' work described below show that there are events that occur continuously over time that are conceived of discretely, not continuously. Julie B. Morrison's dissertation research will explore cases, both concrete and abstract, where according to our analysis animation is expected to facilitate or not to facilitate.

Jeff Zacks has been working with me on event perception, categorization, and description. We selected familiar and unfamiliar events based on a norming study. The familiar events are making a bed and doing the dishes and the unfamiliar ones are fertilizing a plant and putting together a saxophone. Events unfold over time and are inherently dynamic. Nevertheless, we have found that people parse them into discrete units, which they break down into finer units. People's descriptions also follow the hierarchical organization. Jeff's next project is to investigate various ways of teaching the events, some of which are dynamic and some of which use stills chosen to be compatible or incompatible with people's parsing of the events.

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Perspective on the Issues of the Conference. I am a developmental psychologist, and my research focuses on the development of spatial cognition, particularly young children’s understanding and use of maps and other symbolic representations of space. One issue that I have studied that is relevant to the themes of the conference concerns the effects of altering how young children conceive of a set of spatial locations on their ability to use a map of the locations. Since the time of the Gestaltists, psychologists have stressed that the interpretation of spatial stimuli is not merely a process of keeping track of individual locations. Instead, people often interpret individual locations as part of an organized or meaningful structure. A classic example is the constellations; ancient navigators organized and described the locations of sets of stars into meaningful patterns. I have been investigating organizing information as a meaningful pattern facilitates children's use of spatial correspondences between maps and referent spaces.

A key advantage of construing locations in terms of meaningful figures is that we can interpret, encode, or describe individual locations in terms of relations between the parts and the whole of the figure. We may say, for example, that a particular star is located within the handle of the Big Dipper, or that a particular city is located in the Panhandle of Texas. This knowledge could facilitate substantially the process of establishing correspondences between locations on small-scale representations and in the represented space. For example, knowing that a specific star is located within a particular part of a constellation can facilitate the process of searching for that star in the evening sky. The meaningful pattern constrains substantially the area through which we must search for the correct star and hence eliminates what could be a tedious and inefficient process of looking for correspondences on the basis of more local relations, such as the knowledge that the target is to the left of several other stars. In addition, organizing locations into meaningful patterns can facilitate memory by creating redundancies and facilitating hierarchical organization. A specific landmark can be encoded or recalled both in terms of spatial relations to other landmarks (e.g., one star is to the right of another) and in terms of a recognizable structure or parts of the structure (e.g., one star is at the edge of Orion's Belt).

I have conducted studies to investigate the development of the ability to interpret sets of locations in terms of higher-order or meaningful patterns. These studies suggest that learning to interpret a set of locations as embedded within an overall structure facilitates children's use of maps to solve search tasks. Children (ages 4 and 5) were asked to use a simple map to find a hidden toy. The 27 hiding locations were paper coasters that were distributed across a 10 ft by 10 ft piece of felt. On each trial, a sticker was hidden under one of the coasters, and the experimenter showed the child the location on a map that represented the hidden location. As shown in Figure 1, the locations were arranged so that they could be construed as forming a meaningful pattern, the outline of a dog. However, only one-half of the children (ages 4 and 5) were informed that the pattern could be interpreted in this way. These children (the dog-informed group) saw a map on which the individual locations were connected with lines; this highlighted the outline of the dog. The remaining children formed a control group; they saw a map that showed the locations of the 27 coasters, but there were no lines to highlight the dog pattern. The children (particularly the five-year-olds) who were informed of the dog pattern performed almost 40 % better than the control group did. This result suggests that by age 5, young children can take advantage of the fact that maps can highlight alternate construals of a set of spatial locations.

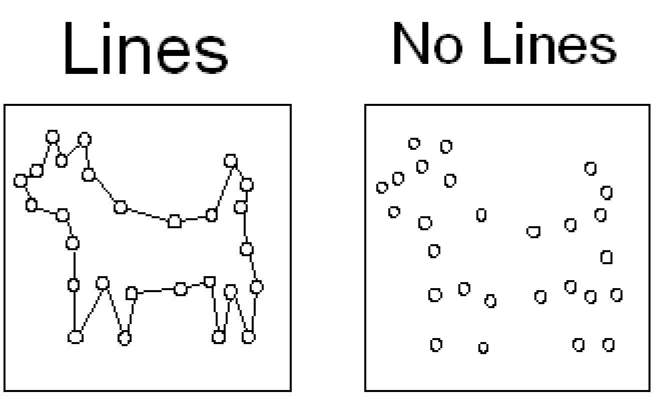

Figure 1. The two displays that children saw.

In several recent studies, we have been investigating how knowledge of a meaningful pattern can be transferred to an otherwise meaningless pattern. Children have first been given experience in using the dog pattern. They are then asked to use a novel pattern that is derived from the dog pattern; the new pattern is a scrambled version of the dog. Children who had prior experience using the dog pattern were able to transfer this knowledge to the novel pattern, but a control group who simply used the new pattern twice performed substantially worse. These results suggest that learning to organize a set of locations into a figure may help to extend children's search skills substantially.

Taken together, these results suggest that learning to think about spatial configurations in alternate ways may be an important aspect of the development of spatial cognition. The results may also be relevant to the themes of the workshop because they highlight the importance of altering how people perceive and think about spatial locations. Dynamic or animated representations of spatial locations have the potential to highlight alternate construals of locations, just as adding lines altered how young children saw the dots on the map. I am interested in exploring these issues further, both on maps and in other types of graphic displays, such as computer animations.

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Cognition, Information Query, and GIS Representation of Geographic Processes

A position paper submitted by May Yuan to the Varenius Workshop on Cognitive Models of Dynamic Phenomena and Their Representations

Introduction

The theme of this position paper accentuates representing geographic processes compatible with human cognition to enable GIS support for information query about process dynamics. Information query support is arguably the most essential function for all information systems, including GIS. Data stored in a GIS will be of little use if important information cannot be extracted from the data. In a GIS, extracting useful information is commonly initiated by user queries. Even when a user is familiar with a GIS, there are three key determinants in the success of a user query: (1) if the user is able to describe the needed information through the interface protocol provided by the GIS; (2) if the requested information is embedded in the GIS databases; and (3) if the GIS is capable of computing and representing the requested information. The position paper stresses that the compatibility of cognitive models and GIS representations is the fundamental issue to all three determinants. Geographic representation needs to account for how users conceptualize geographic worlds and what forms of information they use to develop and address their understanding of the worlds.

Cognitive models and GIS representation

Representation is the conceptual core of an information system. A representation scheme determines data elements and their associations, which an information system can use to hold data and depict reality. Obviously, an information system cannot support the kinds of information that its representation schemes cannot incorporate. Because of a strong cartographic tradition, GIS representation has followed the map metaphor to portray reality as a 2D static world. The map metaphor fits well with cognitive models that we use to acquire slowly changing large-scale environments, type C and D spaces in Zubin=92s space typology (Zubin 1989). Maps arguably "are the most efficient and effective way of communicating metric properties of larger scale places, especially configurations" (Montello 1998, p. 151). A GIS based on these 2D static representations provides sufficient support for location information query and computing, such as geometry manipulation, spatial search, overlay, and buffering.

However, geographic processes are dynamic; cognitive models of processes are much more complicated than the above map-based models. Processes consistently evolve and interact with other environment factors in space and time. Processes are usually organized in a hierarchical structure in which processes at a higher scale tend to control the behaviors of processes at a lower scale. Using wildfires as an example, previous studies of the author (Yuan and Albrecht 1996, Yuan 1997) revealed that there are four models of wildfires needed to support analysis and modeling of fire danger, fire behaviors, fire effects, and fire history. The four models are derived through written materials analysis and user interviews, which also suggest these are the models used by researchers and practitioners for information and knowledge acquisition about wildfires. Combination of the four models form an information life cycle through spatial or temporal aggregation to support transforming information from one model to another (Figure 1), compatible with how users apply knowledge about wildfires from study to study. The information cycle also accommodates the needs for multiple views of a fire process as progression energy exchange among plants and the atmosphere (location snapshots with updates of fuel and weather conditions), fire entities moving across a landscape (entity model with fire runs across space through time), environmental impacts of burns (fire effects and environment recovery in burnt areas), and spatiotemporal mosaics of historical burns (fire mosaics).

Although the information cycle is based on wildfire studies, it can be generalized to depict three information elements essential to understanding geographic processes: process, space, and time. Furthermore, the information elements can be used to identify cognitive models of geographic processes. A key cognitive question on geographic processes is how do we determine each of the three information elements. Do we have pre-defined spatial units and time steps to describe process conditions at individual locations (location snapshots)? Do we have an identified process and use the process to determine space and time according to its rate of spread (fire entity)? Do we use the footprints of a process to determine space and have time arbitrarily defined according to observations (entity snapshot)? Or do we define space by a set of process footprints and have time determined by the occurrences of these processes (fire mosaics)? Information we seek to further understand a geographic process depends on how we perceive the process and our prior knowledge. Each of the above four cognitive approaches results in distinct information needs and challenges a GIS to represent the needed information and provide operations for query and analysis to produce the information from its databases.

Representing geographic processes in accordance with cognitive models

Representing geographic processes in concert with information structures and needs in cognitive models can greatly enhance information support and usability of a GIS. The above four cognitive approaches can be generalized into two alternatives to perceiving geographic processes: (1) from location, time, to processes (location snapshot and fire mosaics), and (2) from processes, time, to location (fire entity and entity snapshots). The former view focuses on information about fire conditions or fire history at individual locations, and the latter view focuses on spatial distribution of fires and burns at different times. The two alternatives suggest a representation scheme to enable bi-directional mappings among processes, time, and space in GIS databases (Figure 2). The representation is distinguished from the map-based model in two ways. First, it applies semantic networks to structure concepts about processes and their elements. Hence, intrinsic structures of processes that correspond to human observations and knowledge of process dynamics are represented explicitly. Hierarchical structures and scale dependency among processes can also be incorporated in the semantic network. Second, it supports bi-directional information linkages so that information can be inferred from processes or locations. Because of the bi-directional mappings of process, time, and space, the representation can facilitate information queries based on either processes or locations. Based on the representation, information can be readily available to support a query about "how a supercell progresses > from t3 to t7?" or "how long location S2 has hail?"

Towards a more powerful geographic information query support in GIS The foundation for a GIS to provide an adequate query support lies in the design of data models and algorithms (Worboys 1990). Users submit queries to a GIS based on their perception and understanding of geographic worlds. Although map-based models handle static geographic phenomena well, adequate GIS query support cannot be achieved without incorporating the approaches that users take to perceive and understand geographic processes. While current GIS map-based representations cannot capture the dynamic aspects of geographic processes, improvements are needed to equip GIS representation to incorporate process behaviors to facilitate spatiotemporal information query and analysis.

The process-based representation framework in Figure 2 greatly enhances information query support for spatiotemporal behaviors of processes, including frequency, duration, movement, and rate of movement. These kinds of information are central to understand geographic processes, but are not easily handled by representation and computation capabilities in current GIS. With the process-based representation, support for frequency queries is straightforward because the number of events occurring in an area can be counted by the number of instances (links) at a location. Likewise, it also eases support for queries about duration by having processes and locations directly linked to the periods during which processes occurred. Furthermore, information about movement or the rate of movement of a process can be computed by tracing time and location objects linked to the process. More information about computing process behaviors based on the process-based representation is discussed in Yuan (1998).

In summary, cognitive models of geographic processes present a basic framework of user perception and understanding. It is also the basic framework for GIS representation to support user queries on the dynamic behaviors of these processes from geospatial databases. Four basic conceptual models of processes are elicited from surveys of users in wildfire studies. By integrating the four basic conceptual models, a process-based representation is proposed. Because the process-based representation is compatible with cognitive models of geographic processes suggested by the four conceptual models, it supports information queries on process behaviors, such as frequency, duration, movement, and rate of movement of processes. Arguably, frequency, duration, movement, and rate of movement are the basic characteristics that we use to understand the behaviors of a process. The compatibility of the process-based representation and cognitive models of geographic processes enhances GIS support for user query and analysis on information about process behaviors.

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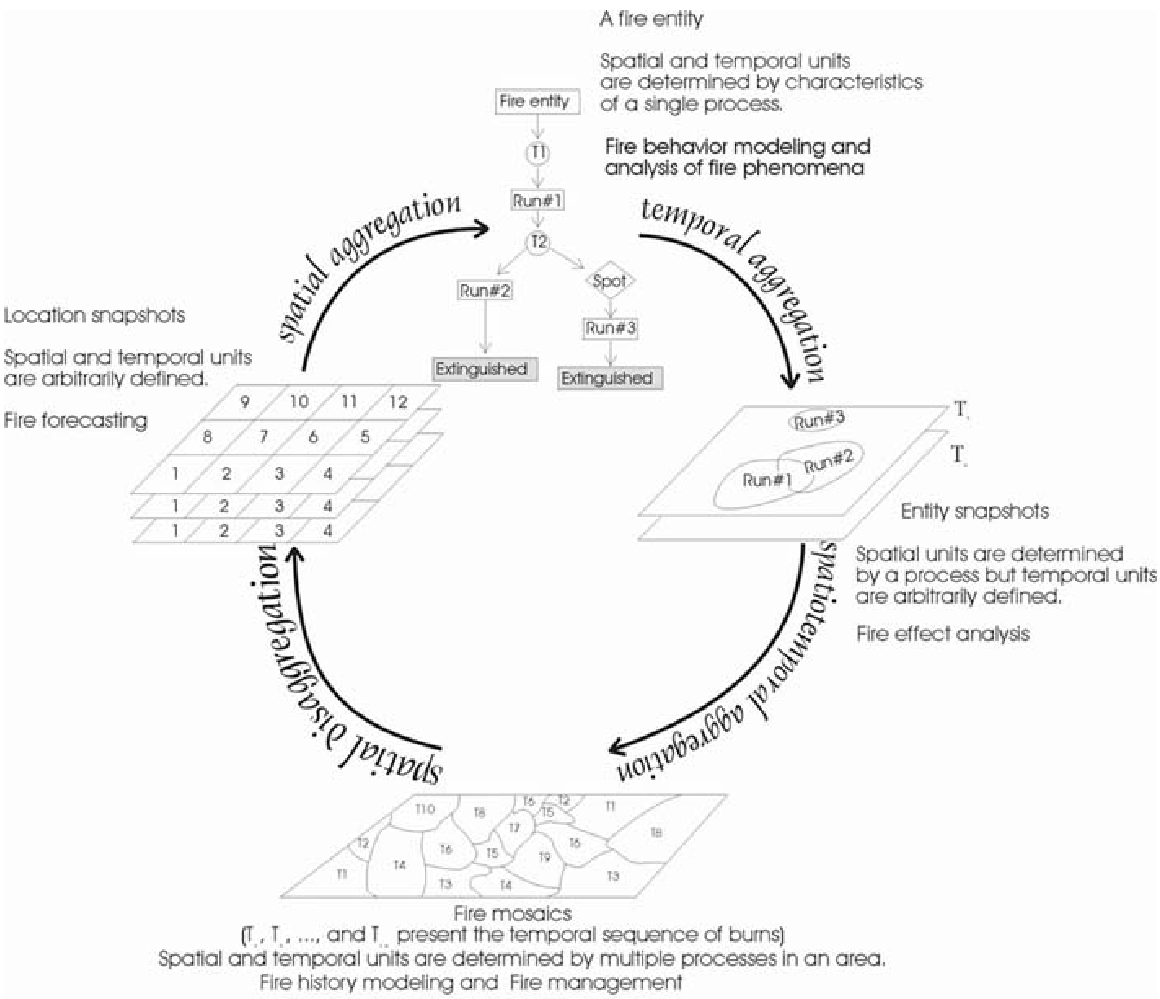

Figure 1: An information cycle for wildfire studies.