Unit 005 - The World in Spatial Terms

by Reginald G. Golledge[1], Daniel Montello[1],
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Unit Topics

- This unit has two primary segments:

  Unit 006 - Human Cognition of the Spatial World, by Dan Montello and

  Unit 007 - Asking Geographic Questions, by Timothy Nyerges and Reginald G. Golledge

Intended Learning Outcomes

- The first section sets the scene by differentiationg between objects and processes and by using fundamental understanding of the spatial world to provide a necessary knowledge base for GIS.

- The second section builds on the knowledge base to demonstrate how specific knowledge about objects and spatial relations among them can be unpacked by the mechanism of asking geographic questions.

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Unit 006 - Human Cognition of the Spatial World

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This section was edited by Reginald Golledge, Department of Geography, University of California Santa Barbara.

Advanced Organizer

Unit Topics and learning outcomes

- This section sets the scene by differentiating between objects and processes and by using fundamental understanding of the spatial world to provide a necessary knowledge base for GIS.

Instructor's Notes

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Metadata and Revision History

Unit 006 - Human Cognition of the Spatial World

1. Introduction

- at human scales, the world consists of objects, events, processes, and a background environment

- the study of cognition is about knowledge: its acquisition, storage and retrieval, manipulation, and use by humans and other intelligent creatures
    - cognition includes sensation and perception, thinking, imagery, reasoning and problem-solving, memory, learning, and language
    - cognitive structures and process are part of the mind, which emerges from a brain and nervous system inside of a body that exists in a social and physical world

- spatial cognition deals with the cognition of spatial properties of the world, including location, size, distance, direction, shape, pattern, movement, and inter-object relations.

- this unit is about spatial cognition and its relevance for Geographic Information Systems

2. Sensing and Perceiving the World

- sensation is the first response of the nervous system to stimulation from patterned energy in the world
    - sensory systems are organized into *modalities*, including vision, hearing, smelling, tasting, pressure and texture, temperature, kinesthesis (limb position and movement), and vestibular senses (gravity and body acceleration)

- perception is the active acquisition of knowledge about the self and the world through the senses

- characteristics of the perceived world:
    - locational perspective -- world perceived from a point-of-view, incomplete access to world
    - redundancy of information (e.g., depth cues of interposition and linear perspective)
    - constancy (color, size, position, shape) -- objects, events, and background maintain many characteristics even as viewing conditions change
    - meaningfulness -- tendency to perceive meaningful, familiar objects and events

3. Cognitive Maps

- are internal representations of the world and its spatial properties stored in memory (also called "mental maps")
    - what's out there, what are its attributes, where it is, how to get there
    - are both idiosyncratic to individuals, and shared among groups

- not like a cartographic map in the head
    - not a unitary representation with a constant scale, not completely integrated
    - consists of discrete pieces (more vector than raster)
        - landmarks, routes and regions

        - pieces determined by physical, perceptual, or conceptual boundaries
    - hierarchically organized pieces
        - multiple levels of pieces differing in status (e.g., size)
        - relation of containment between levels
        - pieces within a level not completely connected
        - hierarchies revealed by patterns of errors or times to respond to questions about
        - the relative locations of places within and between pieces
    - spatial information not well modeled by metric geometries (such as high school Euclidean geometry)
    - emotional associations too (connotative meaning)

- distortions in cognitive maps
    - distortions tell us about properties of cognitive maps
    - how is accuracy of knowledge defined?
        - correspondence to physical measurement
        - group consensus
        - behavioral adaptiveness (does it work?)
    - examples
        - continents are aligned, e.g., South America is thought to be due south of North America when it is actually southeast
        - road intersections and barriers increase apparent distances between places
        - turns are remembered more like right angles and curved lines are often straightened

4. Spatial Learning and Development

- *learning* is a relatively permanent change in cognition or behavior that results from practice or experience

- spatial knowledge is learned via one or more *media of acquisition*
    - direct sensorimotor experience, maps, models, photos and drawings, movies and videos, verbal and written language, virtual spaces
    - media has consequences for nature of acquired knowledge

- cognitive development is systematic change in the content and process of cognition over time, including learning, maturation, and growth (child or adult)
    - child psychologist Piaget known for a qualitative "stage theory" of cognitive development of children
        - change from concrete sensorimotor space in infancy to abstract spatial reasoning in adolescence
        - "frame of reference" used to define locations changes from egocentric (self-centered) to allocentric (externally referenced)
        - geometry of spatial knowledge changes from topological to projective and metric
    - information-processing approach provides an alternative theory of continuous and quantitative development

- traditional theory of developmental sequence in spatial knowledge of the world inspired by Piagetian theory; consists of 3 stages or elements, acquired over time
  - first is "landmark knowledge": unique patterns of perceptual events that identify a place
  - second is "route knowledge": sensorimotor routines that connect ordered sequences of landmarks; little or no metric spatial knowledge
  - third is "survey knowledge": two-dimensional layout knowledge of simultaneous interrelations of locations; allows detouring, shortcutting, and creative navigation

- information-processing approach inspires an alternative sequence of continuous and quantitative increase in extent, accuracy, and completeness of sometimes crude metric spatial knowledge

5. Navigation

- navigation is coordinated and goal-directed route following through space

- "metaphorical navigation" through a math problem, text, computer menu system, computer network

  - consists of 2 components: locomotion and wayfinding

    - locomotion is guidance through space in response to local sensorimotor information in immediate surrounds

      - find support surfaces, avoid obstacles and barriers, follow beacons, move through openings
      - modes: crawling, walking, bikes, cars, planes, etc.

    - wayfinding is planning and decision-making in response to nonlocal information, undertaken to reach goal

      - route-choice, destination scheduling, orientation to nonperceptible features, giving directions

- two fundamental processes of orientation during navigation
  - landmark-based or pilotage ("taking-a-fix") is orientation by recognition of external features
  - dead reckoning is orientation relative to a start location by integrating information about velocity or acceleration during movement, without reference to recognized features

- navigation is carried out via skills that vary in their demands on attentional capacity
  - relatively automatic skills do not demand much attention, such as locomotion in "normal" environments, following familiar routes to work, etc.
  - controlled or effortful skills demand focussed attention, such as wayfinding in unfamiliar environments, giving directions, etc.

6. Using and Learning Maps

- major purpose of cartographic maps is to communicate geographical information and support geographical problem-solving
    - how do maps effectively communicate?
        - humans fantastic at quickly extracting great amounts of information from spatial depictions (images) like pictures or graphs
        - even nonspatial or nonperceivable information can be displayed this way (visualization or spatialization)
        - maps use convenient scales and viewing perspectives (you can perceive all from a single viewpoint)
        - maps highlight and clarify relevant properties; omit or downplay irrelevant properties
    - how can maps confuse or distort communication?
        - projections, generalizations, exaggerations, omissions may mislead or distort knowledge
        - scale translations between maps or between map and world are difficult
        - perspective translation from overhead to terrain-level view may be confusing
        - interpretation of symbols (colors, point symbols, contour lines) may be difficult or misleading

- training and experience with maps changes the way they are perceived and interpreted

- maps show robust "alignment effects", especially when used for navigation
    - confusing if not oriented with the top of map as the direction you are facing when viewing it (such as "you-are-here" maps)
    - such misalignment causes errors and delays

7. Spatial Language

- spatial information often expressed verbally

- giving verbal directions, spatial descriptions in stories, road signs, computer queries

    - producing spatial language often requires translation of nonverbal spatial knowledge, which can alter the knowledge

    - some properties of spatial language

        - nearly all grammatical classes can express spatial information, but especially prepositions

            - prepositions often ambiguous, difficult to translate into other languages
            - "the house on the lake" vs. "the boat on the lake"; "water in a cup" vs. "crack in a cup"

language expresses mostly nonquantitative or imprecise quantitative ("fuzzy") information about space; connections and general location more important

- for example, we say "turn left at the gas station", not "turn 80° after you go .6 miles"
- quantitative precision usually unnecessary or even confusing for verbal communication (not always)

- context is critical in interpreting spatial language
  - context provided by who is speaking, situation, preceding events, etc.
  - spatial quantity terms: near, far, small, large
  - spatial location terms: here, there, left, right
- language often uses spatial metaphors for nonspatial concepts
  - examples: "roundabout argument", "lost in life", "success is dead ahead", "encroach on my space"

- verbal directions
  - person giving directions makes assumptions about questioner's ability to understand the directions
  - what makes the best directions?
    - landmarks and actions only, or an overall description of the space?
    - how do gestures and maps help? how are they combined with words?
    - how much quantitative precision is best?
    - should corrective or overshoot statements be given?
  - many ambiguities in verbal directions
    - what's a block? what's an intersection? what's a right turn when 5 streets come together?
    - "you can't miss it": what does that mean, why do we say it, how do we decide when to say it?

8. Relevance to GIS

- GISs are frequently difficult to use effectively and efficiently and have not nearly reached their potential
  - costs more time and money than it needs to, is more difficult and unpleasant to use than it has to be, and does not perform all of the tasks that it might

- limitations and problems could be improved with greater attention to cognitive issues in GIS
  - how do humans acquire, reason about, and communicate knowledge with GIS
  - cognitive issues touch on all three major functions of GIS: the storage, representation, and analysis of earth-referenced data

- some examples of cognitive issues in GIS
  - how experts and laypeople conceptualize and reason about geographical space,

and how GIS can be designed and taught to support both classes of users
    - how people express spatial information in natural language (such as English), and how this can be used to understand communication with a GIS in natural language (such as a navigation computer inside a car)
    - how interfaces should be designed to promote accurate and efficient communication of spatial and geographic information, such as scale, uncertainty, and network structure

9. Exam and Discussion Questions

1. Discuss ways that the cognitive map is like and unlike a cartographic map. Give some examples of phenomena that support your position.
2. The traditional theory of how spatial knowledge develops over time in a new environment is inspired by the child psychology of Piaget. Describe this traditional theory. What sorts of evidence would support various parts of the traditional theory? What sorts of evidence would argue against parts of the traditional theory?
3. There is a great deal of interest in creating GISs that can directly communicate with users in their own language. Discuss at least two applications where this goal makes sense. Considering the properties of language, especially spatial language, what are some of the problems that must be solved to make language-competent GISs a reality?
4. An argument has been made above that GIS can be improved by understanding human perception and cognition. Review and discuss this argument. In what ways do you agree or disagree with the argument?

10. References

Reviews of perception and cognition may be found in any psychology textbook in those areas.

- Golledge, R.G., 1987. "Environmental cognition", in D. Stokols and I. Altman, editors, *Handbook of environmental psychology*. Wiley, New York, 131-174. Reviews 25 years of research in geography, psychology, and related disciplines.

- Mark, D.M., and A.U. Frank, editors, 1991. *Cognitive and linguistic aspects of geographic space*. Kluwer Academic Publishers, Dordrecht, The Netherlands. Contains many chapters examining cognitive and linguistic issues in GIS from a variety of disciplines.

- Montello, D.R., and S.M. Freundschuh, 1995. "Sources of spatial knowledge and their implications for GIS: An introduction", *Geographical Systems* 2:169-176. Concise overview of several perceptual and cognitive issues relevant to GIS.

- Tversky, B., 1992. "Distortions in cognitive maps", *Geoforum* 23:131-138. Readable and concise review of research on the structure of cognitive maps, patterns of distortions, etc.

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Human Cognition of the Spatial World (006)

Instructors' Notes

- This section has two primary segments: 1.1.1, Human Cognition of the Spatial World (prepared by Dan Montello), and 1.1.2, Asking Geographic Questions (prepared by Timothy Nyerges and Reginald G. Golledge). The first section sets the scene by differentiating between objects and processes and by using fundamental understanding of the spatial world to provide a necessary knowledge base for GIS. The second section builds on that knowledge base to demonstrate how specific knowledge about objects and spatial relations among them can be unpacked by the mechanism of asking geographic questions.

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Unit 006 - Human Cognition for the Spatial World

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Unit 006 - Human Cognition of the Spatial World

Metadata and Revision History

1. About the main contributors

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7. Other contributors to this unit

- Reginald R. Montello

8. Revision history

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Unit 007 - Asking Geographic Questions

by: Timothy L. Nyerges, Department of Geography, University of Washington, and
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This section was edited by Reginald Golledge, Department of Geography, University of California Santa Barbara.

Advanced Organizer

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Metadata and Revision History

Unit 007 - Asking Geographic Questions

1. Introduction

- Questions are designed to encourage thinking and learning.
    - They do this by posing a problem which requires an answer.

- Answers sometimes involve creatively integrating, rearranging, or manipulating bits of information stored in long-term memory or currently being perceived.
    - Often hitherto unnoticed connections between facts or constructs may be made when answering a question.

- Deriving inspiration from Slater's monograph *Learning Through Geography* (1982), Nyerges has developed a set of critical thinking questions to stimulate students' curiosity about geography and GIS (Nyerges, 1991).

- Nyerges (1991) suggests that geographic questions can be categorized into those dealing with:
    1. location and extent;
    2. distribution and pattern or shape;
    3. spatial association;
    4. spatial interaction; and
    5. spatial change.

- In documenting some of the essential steps and stages one goes through when asking and solving geographic questions, the following material draws extensively on the works of Piper (1976), Slater (1982) Nyerges (1991), and Golledge (1996).

2. The process of enquiry

- To begin, consider the following summary of the process of enquiry
    - Table 1 - The process of enquiry - the skills dimension

- To elaborate on the above table, Slater (1982) and later Nyerges (1991) have discussed each of the tabular components in the following ways.

2.1. Research the Questions and Gather Data

- Step 1: Identify and clarify questions, issues and problems.

    1. Identify central questions and issues.
    2. Identify value questions.
    3. Detect ambiguity and vagueness of statement.
    4. Restate questions, problems, issues in clear, precise, unambiguous terms.
    5. Identify elements of a question, problem, issue in need of further clarification.
    6. Identify the "valuing" elements in a question, issue, problem.
    7. Identify areas of conflict (especially conflicting values) in a question, issue, problem.
    8. Identify areas in need of investigation.
    9. Distinguish between direct questions and hypothetical questions.
    10. Formulate hypotheses.
    11. Identify appropriate procedures for testing hypotheses.

- Step 2: Gather and organize data.

    1. Locate data.
    2. Locate sources of data.
    3. Use of data gathering techniques (e.g. sampling, surveys, questionnaires, interviews, content analysis, focus group, case studies and so on).
    4. Select appropriate data.
    5. Record data.
    6. Classify data.
    7. Summarize data.
    8. Present data.
    9. Select appropriate techniques for treatment of data.

2.2. Process the Data

- Step 1: Interpret the data.

    1. Understand form in which data is presented.
    2. Retrieve basic information from single data source.
    3. Retrieve detailed/less obvious information from single data source.
    4. Retrieve complex information from single data source.
    5. Retrieve information requiring use of more than one data source.
    6. Compare data from different sources.
    7. Distinguish between fact and opinion/speculation.
    8. Distinguish between specific facts and general facts (empirical generalizations)
    9. Distinguish between factual statements and conditional or hypothetical statements.
    10. Distinguish between factual statements and value judgements.
    11. Distinguish between factual statements and normative statements.

- Step 2: Analyze the data.

    1. Recognize underlying assumptions.
    2. Following a line of argument (especially where this from an unfamiliar/unconventional point of view)
    3. Determine the point of view of author.
    4. Detect logical flaws in an argument.
    5. Detect unwarranted assertions, inferences, conclusions, etc.
    6. Detect relationships, e.g., causal, chronological, concurrent, etc.
    7. Make warranted inferences/extrapolations from the data.
    8. Make warranted interpolations where there are gaps in the data.
    9. Draw warranted conclusions from the data.
    10. Make warranted predictions of trends, consequences, etc. from the data.
    11. Discern factors which may affect the accuracy of predictions.
    12. Formulate hypotheses to account for effects observed in the data.

- Step 3: Evaluate evidence.

1. Recognize stereotypes and cliches.
2. Detect emotive elements in the presentation.
3. Detect bias and prejudice in the presentation.
4. Detect motive/purpose in the presentation.
5. Detect persuasive techniques used in propaganda, advertising, etc.
6. Distinguish between verifiable and unverifiable data.
7. Distinguish between relevant and irrelevant information.
8. Distinguish between essential and incidental information.
9. Assess the adequacy/ inadequacy of data.
10. Assess the appropriateness or inappropriateness of the data.
11. Determine the consistency/inconsistency of the data.
12. Determine whether facts support a generalization, conclusion or inference.
13. Assess the reliability of data sources.
14. Recognize limitations/qualifications in the data.
15. Distinguish between anecdotal evidence and objective data.

2.3. Reach and Apply Generalizations

- Step 1: Generalize.

    1. Detect common elements in data.
    2. Detect relationships in data which could lead to valid generalizations.
    3. Detect limitations/deficiencies/gaps in data which could render generalizations valid.
    4. Modify or reject hypotheses on the basis of evidence.
    5. Formulate valid generalizations.
    6. Recognize limitations/ probability factors in generalizations involving appropriate phenomena in a geographic context.
    7. Recognize the tentative nature of generalizations involving phenomenon in a geographical context.
    8. Discern factors (e.g., change) which may affect the validity of generalizations.

- Step 2: Draw conclusions.

    1. Suggest tentative solutions to making tentative decisions in relation to questions/issues/problems.
    2. Posing alternative solutions of decisions to problems.
    3. Examine relative merits of alternative solutions or decisions to problems.
    4. Propose suitable courses of action in relation to problems in a geographical context.
    5. Propose appropriate techniques for reaching generalizations and finding solutions to questions/issues/problems of a geographical nature.
    6. Predict probable consequences of a course of action/inaction.
    7. Identify areas in need of further evidence or investigation.

- Step 3: Make value judgments.

    1. Formulating reasoned value judgments.

2. Defend a value position.
3. Examine the implications of alternative value positions.
4. Suggest resolution of value conflicts.

2.4. Re-Evaluate

- Step 1: Re-evaluate the decision.

3. Examples of geographic questions

- While Piper, Slater and Nyerges provide a very detailed framework that a researcher should go through when posing and elaborating geographic questions, we return now to Slater (1982) for specific examples of the types of questions that geographers should be prepared to ask.

- The set of questions that Slater suggests should be in every geography inventory include the following:

  - Where is it?
  - Where does it occur?
  - What is there?
  - Why is it there?
  - Why is it not elsewhere?
  - What could be there?
  - Could it be elsewhere?
  - How much is there at that location?
  - Why is it there rather than anywhere else?
  - How far does it extend already?
  - Why does it take a particular form or structure that it has?
  - Is there regularity in its distribution?
  - What is the nature of that regularity?
  - Why should the spatial distributional pattern exhibit regularity?
  - Where is it in relation to others of the same kind?
  - What kind of distribution does it make?
  - Is it found throughout the world?
  - Is it universal?
  - Where are its limits?
  - What are the nature of those limits?
  - Why do those limits constrain its distribution?
  - What else is there spatially associated with that phenomenon?
  - Do these things usually occur together in the same places?
  - Why should they be spatially associated?
  - Is it linked to other things?
  - Has it always been there?
  - When did it first emerge or become obvious?
  - How has it changed spatially (through time)?

- What factors have influenced its spread?
- Why has it spread or diffused in this particular way?
- What geographic factors have constrained its spread?

4. Conclusion

- Slater (1982) argues that
  - in order to answer some of these questions, geographical investigation requires that individuals practice their skills of observing, defining, classifying, analyzing, inferring, reasoning, integrating, and associating phenomena, and
  - doing so will train both the teacher and the students in the use of geographic thinking and transfer their ability to handle the processes which, if followed, can help solve geographic problems in new environments and in new problem situations.

- Thus to both ask and answer geographic questions, students should be provided with
  - a template of the concepts used in geography (e.g., location, distribution, pattern, shape, association, hierarchy, network, etc., see Golledge (1996)) and with
  - an outline of the processes involved in thinking geographically (e.g. observing, defining, interpolating, spatially associating, and so on, see Nyerges (1991)).

- Together the template and the process assist not only in handling specific questions but also with linking questions that may not otherwise appear to be linked.

- The ultimate aim is to develop an ability to understand what and where things are and how and why they are where they are.

- The ability to state and answer geographic questions implies the existence of informed persons who
  - can see meaning in the way things occur or are deliberately arranged in space,
  - are capable of unpacking spatial relations between and among people, places, and environments,
  - are capable of developing and using geographic skills and spatial abilities, and
  - are capable of examining ecological, spatial and social perspectives to understand various life situations.

5. Relevance to GIS

- GIS can help form, generate, and define geographic questions as well as help solve them.

- By enabling representations of data to be displayed and visualized, GIS helps with identification and definition (i.e., generating "what" and "where" questions) as well as solving them by using various display modes.

- Questions of association can be illustrated with overlay procedures.
- Questions of change can be generated from sequential "snapshots" of locations, patterns and distributions.
- A variety of analytical functions help solve "why" questions, and a selection of methods can be used to examine questions of methodology and process.

- In particular, the instructor should provide:
  - examples of GIS functionalities and the questions they generate
  - examples of GIS methods and the problems to which they apply
  - examples of using GIS to change the naïve geographer into an expert
  - examples of phrasing questions in different formats (verbal, graphic, pictorial, mathematical).

6. Key References

- Piper, K. (1976) *Evaluation and the Social Sciences, National Committee on Social Science Teaching,* Australian Government Planning Service, Canberra, ACT, Australia
- Slater (1982) *Learning through Geography,* Heineman Educational Books, Ltd. London, UK
- Timothy L. Nyerges (1991) Analytical Map Use. *Cartography and GIS*, 18
- Reginald G. Golledge (1995) Spatial Primitives. In Nyerges, T.L., Mark, D.M., Laurini, R., and Egenhofer, M.J. (1995) *Cognitive aspects of human-computer interaction for Geographic Information Systems*. Proceedings of the NATO Advanced Research Workshop , Palma de Mallorca, Spain, March 20-25, 1994. NATO ASI Series D: Behavioural and Social Sciences - Volume 83. Dordrecht, The Netherlands: Kluwer Academic Publishers.
- NCGE and National Geographic Society, *Geography For Life*. (1994)

7. Discussion and Exam Questions:

1. How does GIS help define and solve geographic questions?

2. How are spatial abilities used to interpret and solve geographic questions/problems?

3. Define the stages involved in generating and solving geographic questions.

4. Slater differentiates between "the Big Question" and others. Explain the nature of geographic questions in each of these categories.

5. Given that one can develop an understanding of the cognitive processes required to comprehend the world in spatial terms, how can GIS be used to relate that understanding to Places and Regions?

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Unit 007 - Asking Geographic Questions

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Unit 007 - Asking Geographic Questions

Metadata and Revision History

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Table 1 The process of enquiry—the skills dimension

	Defining the questions, issues, problems		Skills Processing the Data			Reaching and applying generalisations		
Data Forms	Identifying and clarifying questions and issues	Gathering and organizing data	Interpreting data	Analysing data	Evaluating evidence	Generalizing	Problem solving	Making value judgements
verbal								
pictorial								
Quantitative (i) graphs								
(ii) tables								
Symbolic (i) Maps								
(ii) diagrams								

SOURCE: based on Piper, K. (1976) Evaluation in the Social Sciences, National Committee on Social Science Teaching, Australian Government Publishing Service.