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D. C. Plaut

Cognitive Maps

1. Introduction

A cognitive map is a representative expression of an individual's cognitive map knowledge, where cognitive map knowledge is an individual's knowledge about the spatial and environmental relations of geographic space. For example, a sketch map drawn to show the route between two locations is a cognitive map—a representative expression of the drawer's knowledge of the route between the two locations. Because a cognitive map represents/demonstrates an individual's geographic knowledge, geographers, psychologists, and others use them as the principle means by which to assess how we learn, process, and store geographic information gained from primary (e.g., walking through an area) and secondary (e.g., reading a map) sources. An understanding of how we undertake these mental tasks is thought to be important because it reveals the fundamental cognitive processes and structures that underlie spatial decision and choice making, and thus spatial behavior—why we choose certain routes, places to visit, locations to live, and so on (see *Spatial Cognition*; *Behavioral Geography*).

2. Cognitive Mapping

The combined process by which we learn, store, and use information relating to the geographic world is

Table 1
Lynch's classification

Category	*Description*
Paths	Paths are the channels along which an individual moves. They may include streets, walkways, railways
Edges	Edges are the linear elements not considered as paths. They are the boundaries between two phases, linear breaks in continuity such as shores or walls
Districts	Districts are the medium-to-large scale sections to the city, conceived as having a two-dimensional extent, which the observer mentally enters, and which have some common identifiable character
Nodes	Nodes are points, the strategic spots in the city into which an observer can enter, and which are the intensive foci to and from which (s)he is traveling. They may be primarily junctions, transportation changeovers, a crossing, or convergence of paths
Landmarks	Landmarks are another type of point-reference. They are usually a physical object such as a building, sign, store, or mountain

known as cognitive mapping, and this term is used to define the field of study which investigates this process. Cognitive mapping as a field of enquiry is relatively young. Whilst there are a handful of studies which predate 1960, the vast majority of research has occurred after this date and the publication of Kevin Lynch's seminal work 'The Image of the City'. Ever since Lynch's ground-breaking book, cognitive mapping research has been a multidisciplinary endeavor, undertaken by geographers, psychologists, anthropologists, computer, and information scientists. However, whilst a vast amount of research has been conducted as yet there is only limited consensus as to the fundamental processes of cognitive mapping. As such, there are a number of theories that seek to explain how we construct, process, and store cognitive map knowledge and how this knowledge is used to make spatial decisions and choices. These theories generally have been formulated on the basis of evidence provided by cognitive maps (see Downs and Stea 1977, Gärling and Golledge 1993, Portugali 1996, Golledge and Stimson 1997).

3. *Cognitive Maps*

Until very recently the bases and processes of human cognitive mapping was exclusively measured and assessed through cognitive (sketch) maps and other external forms of knowledge representation (e.g., estimating distances). More recently these methods of data generation have been supplemented by qualitative and neurological approaches. Moreover, there has been a transference of experimental setting from the laboratory to the natural environment.

Whilst a cognitive map is any 'map' which represents an individual's knowledge of an area, it generally takes the form of a sketch map drawn on a sheet of paper (it could, however, be a drawing in sand or a map constructed out of natural material). In experimental conditions, subjects are given a sheet of paper and are asked to draw a map of a certain location, area, or route between locations. The scale of the geographic realm to be drawn can vary substantially from the global (e.g., draw a map of the world) to the local (e.g., draw a map of your neighborhood). Variants on this simple sketch mapping exercise include providing respondents with a small portion of the map to provide a scale and reference, and teaching subjects a sketch map language where specific symbols are used to denote particular features. By aggregating together the cognitive maps of several individuals it is possible to determine their shared level of knowledge and which elements of an environment are most salient. This is the technique pioneered by Lynch. He analyzed individuals maps by classifying their elements into five different classes (see Table 1) which he then used to produce a composite map where the symbol size/shading density is proportional to the number of times an element appeared on the individual maps. Using this technique he aggregated together the sketch maps of residents in Boston, Jersey City, and Los Angeles to create composite cognitive maps of these cities (see Fig.1)

The analysis used by Lynch is a content classification. A number of other classification schemes have been used to analyze cognitive maps. For example, there have been classifications that assess map style, structure, and accuracy. In these cases the focus moves beyond what elements an individual draws to assessing the relationship between the elements and their relativity to the real world. In addition, the accuracy of the spatial relations portrayed can be analyzed statistically using spatial statistics. For example, in many studies bidimensional regression has been used to compare the geometry of the cognitive map to a cartographic map. Bidimensional regression is a two-dimensional equivalent of linear regression that quantifiably assesses scale, rotation, and translation differences between the actual and estimated pattern of responses.

Using the technique of sketch mapping to generate data about a person's cognitive map knowledge and

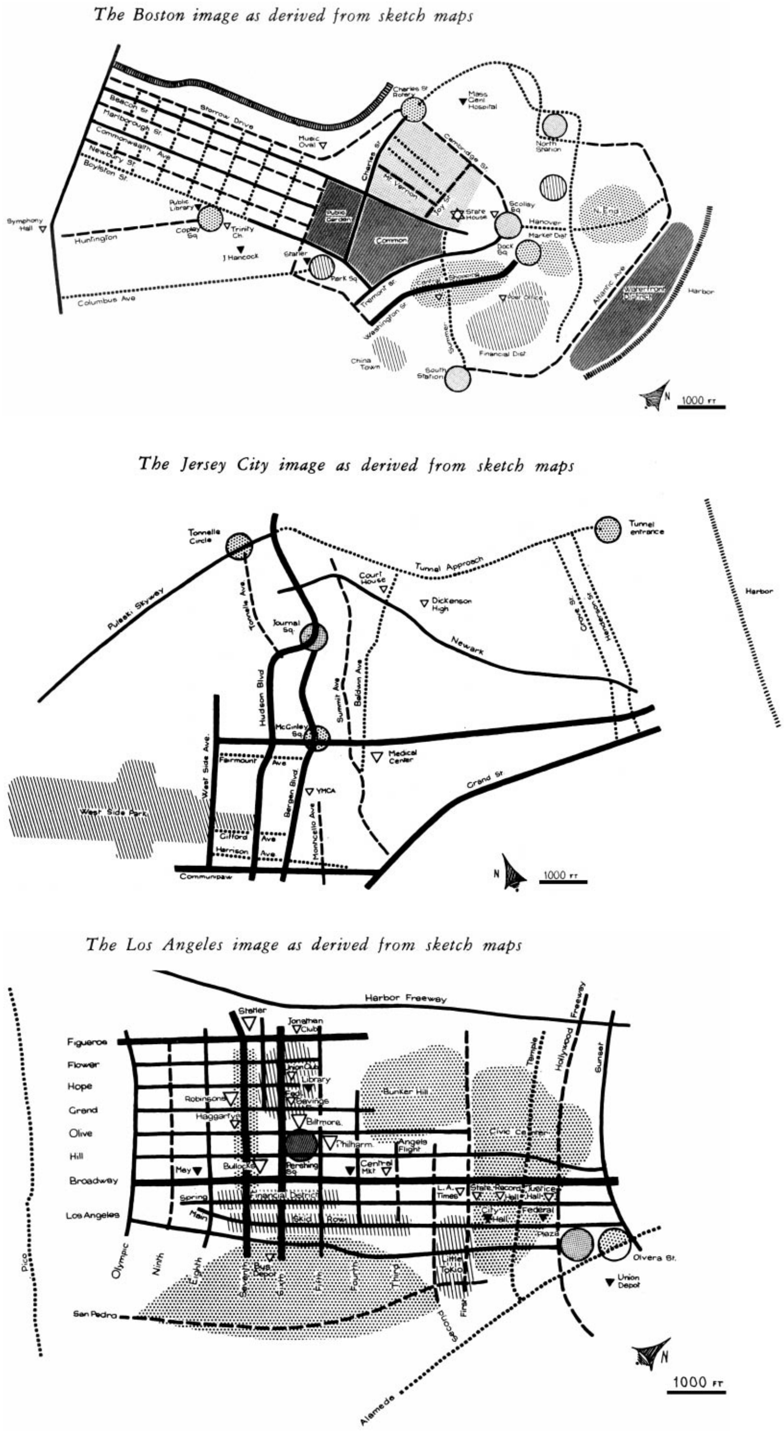

Figure 1
Cognitive maps of Boston, Jersey City and Los Angeles

their ability to use this knowledge is not without criticism. For example, a number of researchers have argued that sketch maps have a number of qualities that make them unreliable and inaccurate measures of spatial knowledge (note not geographic knowledge): they are dependent upon drawing abilities and familiarity with cartographic conventions; they suffer from associational dependence where later additions to the sketch will be influenced by the first few elements that are drawn; their content and style are influenced by the size of paper used for sketching; they are difficult to subjectively score and code; and they often show less information than the respondent knows. As a consequence of these criticisms it is becoming less common for researchers to use sketch mapping as an analytical tool to assess individual and collective cognitive mapping. Instead, researchers are turning to a range of other techniques.

4. *Other Ways to Measure Cognitive Map Knowledge*

4.1 *Other Action Measures*

Other forms of action (e.g., drawing) measures can be divided into those that, like sketch mapping, are two-dimensional in nature and those that are unidimensional. Other two-dimensional measures include completion tasks and recognition tasks. Completion tasks require an individual to complete a task that has already been started for them. For example, spatial cued response tests require subjects to place locations in relation to locations that are preplaced. A highly cued version of this are cloze procedure tests that require a subject to 'fill in' a missing space (an aspatial example of which would be, 'a dog barks but a cat ------?' Recognition tasks measure how successful subjects are at identifying spatial relationships. Iconic tests require the respondent to identify correctly features on a map or aerial photograph. Configuration tests require a subject to identify correctly which configuration, out of several, displays the correct spatial relations. Verifiable statement tests require subjects to identify whether a textual description of a spatial relationship is true or false. Spatial cued response data are often analyzed like sketch maps using bidimensional regression.

Cloze procedure and recognition tests are analyzed by constructing an accuracy score that reveals as a percentage the number of correct placements or recognitions.

Unidimensional tests seek to uncover one-dimensional aspects of cognitive map knowledge such as distance and direction. These dimensions are thought to be representative of spatial knowledge in general, but are particularly useful for measuring levels of route (procedural) knowledge. Distance tasks are used to assess an individual's knowledge of the distance between locations. In his review, Montello (1991) identifies five groups of tests designed to measure cognitive distance estimates: ratio scaling, interval and ordinal scaling, mapping, reproduction, and route choice. Ratio scaling adapts traditional psychophysical scaling techniques to a distance context, with subjects estimating the distance to a location as a ratio of some other known distance, such as an arbitrary scale or the length of a ruler. Interval and ordinal scaling are similar to ratio scaling but differ in their level of measurement: paired comparison requires a respondent to decide which one of a pair of distances is longer; ranking requires a respondent to rank various distances in order along the dimension of length; rating requires a respondent to assign the distance between places to a set of predetermined classes that represent relative length; partition scales require a respondent to assign distances to classes of equal-appearing intervals of length. Mapping is the measurement of distances from a sketch map for comparison with the actual distances. Reproduction requires a respondent to provide distance estimates at the scale of the estimated distance. Route choice consists of inferring judgments of cognitive distance from the choice of route an individual makes when asked to take the shortest route between two locations.

Like sketch map data, distance data can be analyzed individually or aggregated beforehand to provide data about a group. A common method to analyze ratio scaling, mapping, and reproduction data is to regress the cognitive distance estimates onto the objective distance values, observing the relationship between the two. Another common strategy, and one also used with interval or ordinal distance data, is to analyze the data using multidimensional scaling techniques (MDS). MDS techniques explore the latent structure of a set of distance estimates by assessing the dimensionality of the data. They do this by constructing a two-dimensional space from one-dimensional data using a series of algorithms. In essence, they construct a 'map' showing the relationship between a number of objects. This 'map' can then be compared to an actual map using techniques such as bidimensional regression.

Direction tasks assess an individual's knowledge of the direction between two locations. The most common direction task is pointing. Pointing involves standing at, or imagining being at, a location and pointing to another location. An alternative technique involves drawing on a compass the direction to a location from another. Direction estimates have been analyzed by comparing the estimates to the actual directions, often through a simple subtraction process. In other cases, a technique of projective convergence has been used to construct a 'map' from estimates by calculating where estimates to the same location but from different sites intersect.

4.2 Qualitative Approaches

In recent years there has been an increase in the use of qualitative methodologies to investigate cognitive map knowledge. In some cases, this has involved a scientific approach and in others an interpretative approach. The scientific approach continues the tradition described above, but rather than externally representing their knowledge through actions (e.g., drawing, pointing) individuals are required to describe verbally routes or layouts in experimental conditions. Like cognitive maps these data can be analyzed for content, style, structure, and accuracy. The interpretative approach, however, is less structured in terms of data collection. It posits that talking to and observing individuals as they interact with an environment reveals information concerning spatial behavior. Such an approach might seek to gain a spatial understanding of an area by adopting a strategy of in-depth interviews, discussing the reasoning behind spatial decision making.

4.3 Neurological Approaches

In contrast to the approaches above, which seek to understand the process of cognitive mapping by examining external measures (action or verbal), neurological approaches measure neural activity within the brain. A set of brain-scan techniques exist, differentiated by their temporal and spatial resolution. Magnetic Electroencephalography (MEG) has a high temporal resolution (0–300 ms) but low spatial resolution (providing only a general indication of neural activity). Positron Emission Tomography (PET) is the converse, with functional Magnetic Resonance Imagery (fMRI) providing a middle ground for both parameters. To reveal information about spatial cognition, scans are taken as the individual undertakes a series of spatial, problem-solving tasks. As such, neurological approaches seek to explain spatial thought and spatial behavior by identifying its neural, physiological bases rather than its psychological basis. To date there has been very little work that has sought to marry the findings of neurological and psychological research to provide a comprehensive, physiological and psychological model of cognitive mapping.

4.4 Naturalistic Settings

Many studies, particularly from psychology, which seek to understand cognitive map knowledge are conducted in controlled laboratory settings. For example, respondents may be required to learn the layout of objects in a experimental laboratory, and then to map the location of objects, or estimate distance and directions between objects. The laboratory is attractive to the researcher because they can control/monitor all the variables that may affect spatial learning and processing. Some researchers, however, question the ecological validity of this approach given that cognitive map knowledge concerns the geographic environment and it is this environment in which spatial behavior occurs. For these reasons they suggest that testing should occur in the natural environment, and increasingly this is becoming more common.

5. Summary

Cognitive maps are representative expressions of spatial knowledge. They are part of a wider set of analytical measures which seek to determine how we learn, store, and process knowledge of the geographic environment. These measures are important because they reveal fundamental aspects of cognition and reveal the cognitive processes that underlie spatial decision and choice making.

See also: Hippocampus and Related Structures; Knowledge (Explicit and Implicit): Philosophical Aspects; Mental Maps, Psychology of; Spatial Thinking in the Social Sciences, History of

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R. Kitchin

Cognitive Modeling: Research Logic in Cognitive Science

Cognitive science is a genuinely interdisciplinary field, which owes its existence to the insight that, in different disciplines, interesting research was based on the common assumption that cognition could be regarded as computation (see *Artificial Intelligence in Cognitive Science*; *Cognitive Science: Overview*). It follows that if cognition is computation, theories of cognition should be specified in terms of representations and the computational steps performed on them. Thus, cogn-

International Encyclopedia of the Social & Behavioral Sciences ISBN: 0-08-043076-7