class intervals that are equally spread across the data range. For example, if the data have a range of 1 to 99 and five classes are desired, then class breaks could be created at 20, 40, 60 and 80.

- *Quantiles:* Divide the number of data values evenly into the number of classes that have been chosen. Thus, if there are to be five classes, each class will contain 20% of the observations.
- *Standard deviation:* Calculate the mean and standard deviation of the data set and then classify each value by the number of standard deviations it is away from the mean. Often, data classed by this method will have five classes (greater than 2, between 1 and 2, between 1 and –1, between –1 and –2, and greater than –2 standard deviations) and will be shaded using two different color ranges (e.g., dark blue, light blue, white, light red, and dark red, respectively).
- *Natural breaks (Jenk's method):* Classes are based on natural groupings inherent in the data. Jenk's method identifies the breaks that minimize the amount of variance within groups of data and maximize variance between them.

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See also Choropleth Map

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Cognitive Science

Cognitive science is the discipline or collection of disciplines that scientifically studies knowledge and knowing in intelligent entities, including humans, nonhuman animals, and synthetic computational entities, such as robots. Cognition includes perception, thinking, learning, memory, reasoning and problem solving, and linguistic and nonlinguistic communication. Increasingly, researchers also integrate the study of affective responses—emotion—into the study of cognition. Questions about cognition are interesting in their own right, but researchers also study cognition because it influences, and is influenced by, overt behavior. For example, what we know about the layout of the environment influences where we choose to travel, while exploratory movements to new locations provide us with knowledge about the layout of that environment. This entry explains the relevance of cognitive science to geographic information science and presents several theoretical approaches for the scientific study of cognition.

Cognitive science is inherently multidisciplinary, and to the degree that new concepts and methods have emerged from the interaction of different disciplines, it is interdisciplinary. Traditionally, since it began in the 1950s, the core disciplines constituting cognitive science have included experimental psychology (particularly cognitive and perceptual), philosophy of mind, linguistics, neuroscience, and computer and information science. Several other disciplines have developed cognitive approaches and contributed to the diverse array of methods and topics in cognitive science, including anthropology, biology, education, engineering, mathematics, physics, and more.

Cognition in Geographic Information Science

Cognitive science, particularly as it concerns itself with human cognition, is an important component of geographic information science. Geographic information is used to help us understand and make decisions about the earth's surface and the spatiotemporal and thematic attributes of the natural and human features and events occurring there. The study of cognition within geographic information science is theoretically motivated by the fact that human understanding and decision making with geographic information are cognitive acts. Likewise, cognition is often related to space, place, and environment; that is, cognitive acts are often geographic. Therefore, cognition is part of the domain of geographic information science, and geography and geographic information are likewise part of the domain of cognitive science.

Specific cognitive issues in geographic information science include the relationship between computer representations (data models, database structures) and cognitive representations of space, place, and environment (cognitive or mental maps, mental models); the design of information displays, including visual and nonvisual displays, and augmented and virtual reality; the communication of complex information about data quality, scale, change over time, and abstract and multivariate information, such as semantic relatedness (as in spatialized displays of nonspatial information); the human factors of navigation and other information systems; the interoperability of information systems across cultures and other domains of conceptual variation; training and education in geography, geographic information science, and related disciplines; and more.

Practically, the study of cognition is motivated by the desire to improve the usability, efficiency, equity, and profitability of geographic information and geographic information systems. Cognitive research holds the promise of improving a wide variety of geographic information systems, including education and training programs, in-vehicle and personal navigation systems, digital geographic libraries, tourism and museum information systems, and systems for those with sensory disabilities. Furthermore, by helping to tailor information systems to different individuals and cultures, cognitive research can potentially increase information access and the equitable dissemination of technologies. Such research may help inexperienced users gain access to geographic information technologies and help experienced users gain power and efficiency in their use of technologies. Cognitive research can also improve education in geography and geographic information at all age and expertise levels.

Theoretical Approaches to the Scientific Study of Cognition

Researchers take a variety of theoretical approaches, or frameworks, to the study of cognition. These approaches are more general than hypotheses or specific theories, providing or suggesting not only concepts and explanatory statements but also specific research questions, research methods, relevant types of data, and appropriate data analysis techniques. In other words, theoretical approaches help researchers design and interpret studies, ultimately in order to achieve the scientific goals of describing, predicting, explaining, and controlling phenomena. This section briefly reviews nine theoretical approaches to the scientific study of cognition: constructivism, information processing, ecological, computational modeling, connectionism, linguistic/category theory, socially and culturally situated cognition, evolutionary cognition, and cognitive neuroscience.

There is a diversity of theoretical approaches in cognitive science for several reasons. Cognitive science emerged from multiple disciplines with different empirical and conceptual traditions, and variations exist even within disciplines. Researchers working in different disciplines and problem areas focus on different parts of the complex nexus of organism-meaning-reality that is the subject of cognitive science. Some problems are relatively low level, not requiring the involvement of much conscious thought; an example is how the visual system recognizes feature shapes in the environment. Other problems are relatively high level, involving a great deal of conscious thought; an example is deciding which apartment best suits one's residential needs. Cognitive phenomena vary in whether they depend mostly on sensing, moving, memory of various types, communication with others, and so on. In other words, different theoretical approaches are partially complementary rather than contradictory. Finally, the scientific study of cognition is relatively young. Consensus does not yet exist as to what to measure, how to measure it, what causes what, and so on. Cognition may be sufficiently complex and contextually dependent so that no single grand theoretical approach will ever comprehensively explain cognition.

Constructivism

Constructivism is the idea that people do not simply receive knowledge passively, but actively construct it by organizing and interpreting perceptual input with respect to existing knowledge structures. Thus, what a person perceives or learns in a new situation critically depends on what he or she already knows. The existing knowledge structures are schematic internal representations—simplified and abstracted models of reality—that can distort knowledge. A constructivist approach within geographic information science is often applied to research on cognitive maps and mental models.

Information Processing

Information processing agrees that human cognition depends on internal models of the world, but it emphasizes people's acquisition and use of cognitive strategies—plans for how to reason and solve problems. For example, researchers studying GIS users can ask the users about their consciously accessible strategies for solving problems, or they can observe the users' patterns of eye movements while viewing the monitor in order to infer their nonconscious strategies. Information processing theorists are interested in people's *metacognition*—what they know about what they know and how they can reason. Metacognition helps determine how and when people use particular cognitive structures and strategies when reasoning about particular problems.

Ecological

The *ecological* approach emphasizes the emergence of cognition as a function of the mutual fit between organisms' perceptual-action systems and the physical environment. According to this approach, knowledge is not internally represented or constructed, but is "directly" available in patterned energy from the structured physical environment (perceptual arrays), picked up by the perceptual systems of moving organisms. Perceptual arrays provide information for the organism about functional properties of the environment, called *affordances.*

Computational Modeling

Computational models express ideas about structures and processes in formal languages, typically equations or other logical/mathematical operations programmed in a computer. Computational models of cognition simulate the "intelligent" cognitive structures and processes of people and other animals, so they are often referred to as *artificial intelligence,* or *AI.* A robot simulates intelligence in an electromechanical entity that senses and acts on the world. Some AI researchers apply logical rules to meaningful representations like concepts, similar to the information processing approach; this is known as *symbolic AI.* Recently, the application of precise formal logic to the computational modeling of cognition has been largely replaced by various probabilistic and imprecise logics, including fuzzy logic and qualitative reasoning.

Connectionism

Some computational modelers incorporate simple, nonsymbolic computational units that are somewhat inspired by nerve cells (neurons). Because the units are linked, sometimes in a very complex manner, this approach is known as *connectionist* or *neural network* modeling. The connections instantiate simple rules relating states of the connected units. The network's output is determined by patterns of connections that affect output from node to node, by increasing or decreasing the chances that a particular node will become active. These patterns change over time as a result of the network's previous outputs or that of other networks. Connectionism is thus thought to offer an approach to cognition that eliminates the need for the symbolic cognitive structures. Geographic information researchers use connectionism to model perceptual and memory processes, as well as many noncognitive phenomena.

Linguistic/Category Theory

Some cognitive researchers focus on the role of *natural language,* often stressing words as labels for semantic categories. What is the nature of semantic categories that represent the meanings of objects and events in the world? It has been convincingly demonstrated that semantic categories generally do not operate by assigning entities to classes according to a finite set of necessary and sufficient characteristics. Instead, they are graded or indeterminate, representing conceptual meaning with related examples or a model of the average or best example (a prototype). Geographic information scientists conduct research on people's concepts of geographic features (their cognitive ontologies), such as mountains, cities, and regions.

Socially and Culturally Situated Cognition

This approach focuses on the role of the *social and cultural context* of cognition and behavior. Cognition serves to solve culturally specific problems and operates within contexts provided by culturally specific tasks and situations. Cognition is, in a sense, embedded in structures provided by culturally devised tools and technologies. Cognition is not just in the mind (or brain) but also in socially and culturally constructed situations. For example, database interfaces designed according to cultural tradition structure how people reason with the databases.

Evolutionary Cognition

An *evolutionary* approach stresses that cognition is shaped by an innate cognitive architecture that has biologically evolved over the millennia of human evolution. This approach disagrees that the mind is a general-purpose problem solver, instead emphasizing the importance of a relatively small set of domain-specific modules specialized to solve certain classes of universally important cognitive problems. A pertinent example for geographic information scientists is how people find their way while navigating in the environment. An evolutionary approach also de-emphasizes cognition as culturally variable, suggesting instead that people from different cultural backgrounds will tend to reason in certain universal ways about particular problems of specieswide relevance.

Cognitive Neuroscience

Cognitive scientists increasingly attempt to explain cognition by explaining the structures and processes of actual brains; at least, they attempt to identify the brain concomitants of mental activity. *Cognitive neuroscientists* study mind-brain relationships with techniques including histological studies of brain anatomy, studies of patients with brain injuries, single-cell recordings of neurons, and electroencephalography (EEG) readings of the activity of groups of neurons. Progress in cognitive neuroscience is greatly accelerating because of the development of scanning technologies to observe brain activities in alert, healthy human research subjects. These include positron emission tomography (PET), computed tomography (CT), and, especially, functional magnetic resonance imaging (fMRI). Cognitive neuroscience has been applied to problems such as language and memory, but geographic information scientists have just begun to explore its potential for their specific problems.

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See also Fuzzy Logic; Mental Map; Neural Networks; Ontology; Spatial Cognition; Spatial Reasoning; User Interface; Virtual Environments

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Computer-Aided Drafting (CAD)

Computer-aided drafting (CAD) is an automated system designed to efficiently and accurately create and display graphic entities at a high level of precision, primarily for use in architecture, engineering, and mechanical design. It is important to note that the CAD acronym is often expanded in a number of synonymous ways: The A can stand for "aided" or "assisted," and D for "drafting" or "design." Other related terms are *computer-aided drafting and design (CADD), computer-aided mapping (CAM),* and *computer-aided cartography (CAC).* CAD is often used to generate parcel, street, and utility maps, which can be used alone or with GIS.

While CAD is similar to GIS, there are several important distinctions between CAD and GIS, and by comparing these systems, we can best describe CAD. The primary distinction is that CAD is designed to create and edit graphic entities and generally has minimal database capabilities, while GIS is a spatial database that uses graphics to display the results of analysis, with graphic editing being a secondary capability. It is worth noting that some CAD programs do provide GIS functionality as an add-on to their core graphic editing functions.

In CAD, properties such as layer name, display color, display width, and text can be attached to graphic entities. In some cases, nonspatial attributes can be attached to specialized point entities. However, these data are generally not available in a tabular format within CAD. In GIS, entitles are directly linked to a database that contains geometric information as well as nonspatial attributes and is readily available in a tabular format.

In CAD, all the graphic entities are generally contained within a single "map" file and are available only through that file. A GIS "map" is a collection of pointers to multiple data files that can be used in other GIS maps.

CAD programs can organize graphic entities into "layers," which are primarily used to control the display of entities by defining colors and linetypes for different groups of objects. CAD layers can also be used to organize entities thematically. For example, all