Spatial concepts

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The term "concept" has been defined in several ways. From the perspective of cognitive science, concepts are mental constructs about the nature of material and abstract things, and the relationships that obtain between them. The words we use in communication – and some would add in reasoning – refer to concepts, and their meanings are shared between individuals to a greater or lesser degree. There is little agreement among the philosophers, linguists, and psychologists who study the nature of concepts as to how such mental representations and lexical concepts precisely relate to language, thought, and activity.

An important branch of geographic information science (GIScience) studies such ontological issues from several perspectives, motivated by the need for better analytical software, better navigational devices, and better geographical education. Spatial information theory has emerged in the past two decades as a blending of interests from researchers in many fields, including geography, cognitive psychology, computer science, and linguistics. The biennial Conference on Spatial Information Theory (COSIT) has become an important meeting ground and publication venue for this multidisciplinary community of interest.

The creation of geographic information and knowledge follows from the gathering of observational data from human senses and mechanical sensors. Understanding the progression of representations involved at each stage of this process is important from both scientific and social theoretic points of view. Because geographic knowledge informs important policy and geodesign decisions, it is essential we understand the sources of error and bias in measurement and interpretation. The need for development of *semantic reference systems* as an essential complement to existing spatial and temporal reference systems has been described by Kuhn (2003) and has motivated considerable research activity on geographical ontologies.

Spatial concepts and spatial reasoning lie at the heart of geography as a multifaceted academic subject, and the professional practice of geography – one that began with the fundamentally spatial tasks of measuring Earth features and describing their spatial relations. Geography's numerous subfields are often classified at the highest level in terms of conceptual or methodological duals: physical and human, quantitative and qualitative, space and place. As the intellectual traditions of geography have multiplied and grown more varied over two millennia, space and spatiality have remained integral to each. However, geographers' conceptions of space are by no means uniform. There has, for example, been considerable debate on whether geography is a "spatial science."

Space, space–time, and place

Broadly speaking, there are in geography two distinctive views of *space*: first, as a fundamental attribute of reality that is, with time, the mathematically describable context for natural phenomena; second, as a count noun standing for human conceptual constructs borne of

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individual experience and societal factors such as power relations. Within the first view, there are distinctive conceptual frames: that of an *absolute*, Newtonian space as "container," normally associated with Euclidean geometry, and that of *relative* space within which distance may be geometric or derived from other relations. The term "place" is often used to refer particularly to the human experience of space. Description affords analysis, and the concepts discussed below are by and large those enabling mathematical and formal-logical spatial analyses.

In modern physics, space and time are understood to be joined as the unbounded continuum of *space–time*, a four-dimensional reality wherein all phenomena are events. Certainly, to exist in a location with certain attributes is to exist there in that state for some period of time. However, those dynamics are not necessarily a focus in any given investigation. Other branches of science, including geography, have sought to develop four-dimensional representations, but have found it generally useful to hold time apart from the spatial dimensions in a "three plus one" model.

The spatial concepts enumerated here should be understood to have an important temporal dimension even where time is not mentioned explicitly.

Universality and ubiquity

Although geography is thoroughly spatial, the most fundamental of spatial concepts are by no means exclusive to geography. There are distinctive disciplinary perspectives on many, and some spatial terms (i.e., lexical concepts) can have multiple meanings. For example, *surface* normally refers to the physical bounds of an object, particle, or organism. In oceanography, surface topology is used to map currents and study climate. Materials scientists study the physical properties and chemical interactions of surfaces as interfaces between phases of matter. The calculations and design choices of structural engineers depend in part on surface stress properties of building materials. The term "surface" also refers to the mathematical description of a two-dimensional field, which is an important analytical construct in geography among many other fields. Finally, *surface* is also used to mean, "that which is superficial or most readily perceived" in any domain.

This example illustrates the way that many core spatial concepts have both a basis in physical reality and important metaphorical meanings in the physical and social sciences, in engineering and other design fields, and in the humanities. Johnson (1987) has argued convincingly that the ubiquity of metaphorical spatial conceptual language stems from the human bodily experience of physical interaction with the world, and proposed corresponding cognitive structures, termed *image schemas*, that represent for example the concepts and experience of *containment*, *path*, *force*, *counterforce*, and *center-periphery*.

Spatial concept taxonomies

There has been a growing impetus to enumerate spatial concepts and to organize them in one or more taxonomies, both within and outside of disciplinary perspectives. The motivations for this include (i) designing instruction in academic subjects such as geography, geoscience, chemistry, and engineering; (ii) designing training to improve spatial reasoning ability at all developmental and educational levels more generally; (iii) developing more usable software for professional practice, including geographic information systems (GIS); and (iv) making useful links between the above requirements and basic research in cognitive psychology and education.

For education

Scientific instruction proceeds through grade levels with the introduction of concepts and conceptual frames of increasing complexity, seen for example in *Benchmarks for Science Literacy* (American Association for the Advancement of Science 1993). Hierarchies of complexity for spatial concepts in geography have been developed by at least two research groups. In one case (Golledge, Marsh, and Battersby 2008), five concept/task tiers are identified: primitive, simple, difficult, complicated, and complex; single examples of concepts for each of those levels are *location*, *distance*, *adjacency*, *scale*, and *interpolation*. In a second case (Jo and Bednarz 2009), three levels are identified: primitive, simple-spatial, and complex-spatial; single examples of concepts for these are, respectively, *location*, *distance*, and *distribution*.

For software design

Spatial analytical software and GIS enable the application of computational methods to research questions by means of specific models and algorithms. These are often instantiated as modular software programs ("tools") applied individually or in sequence upon spatial data. Choosing the correct tool or tools to use for answering a particular question, from a library of hundreds, is problematic. This problem could be mitigated by organizing such tool libraries according to some spatial conceptual logic, preferably informed by cognitive studies and our improving understanding of hierarchical concept complexity. The structure for such organizing models could range from simple thesauri specifying *broader*, *narrower*, and *related* relations, to formal ontologies.

For improving spatial ability

There has been considerable psychological research on spatial cognitive ability in the past several decades, and there is now a common understanding that spatial ability is not monolithic, but rather multifaceted, making it more realistic to speak of multiple spatial abilities. That is, there are distinctive components involved, and individuals may be differentially competent at each. Recent research has shown that performance at some spatially demanding tasks can be improved by training and other interventions (e.g., Newcombe and Frick 2010).

A taxonomy adopted by cognitive psychologists (Newcombe and Shipley 2014) is based on two conceptual divisions. The first is between concepts concerning the internal structure of objects and those concerning objects' locations in the world. The second is between static representations of such structure and position, and their dynamic nature and representation. This suggests four broad categories of spatial skills, which may be extended to concepts: *intrinsic-static*, *intrinsic-dynamic*, *extrinsic-static*, and *extrinsic-dynamic* (Figure 1). It should be noted that many spatial concepts do not fit neatly within a single category. For example, clusters are defined by spatial relationships within a reference frame, and have identity as objects unto themselves, with structural characteristics such as density.

Developing a universal taxonomy of spatial concepts has proven to be difficult, as spatial concepts seem to defy narrow classifications. This suggests multiple taxonomies will be useful, for different purposes. This entry does not attempt a strict ordering; rather, it enumerates a number of the fundamental spatial concepts in narrative fashion within the broad thematic groupings that follow.

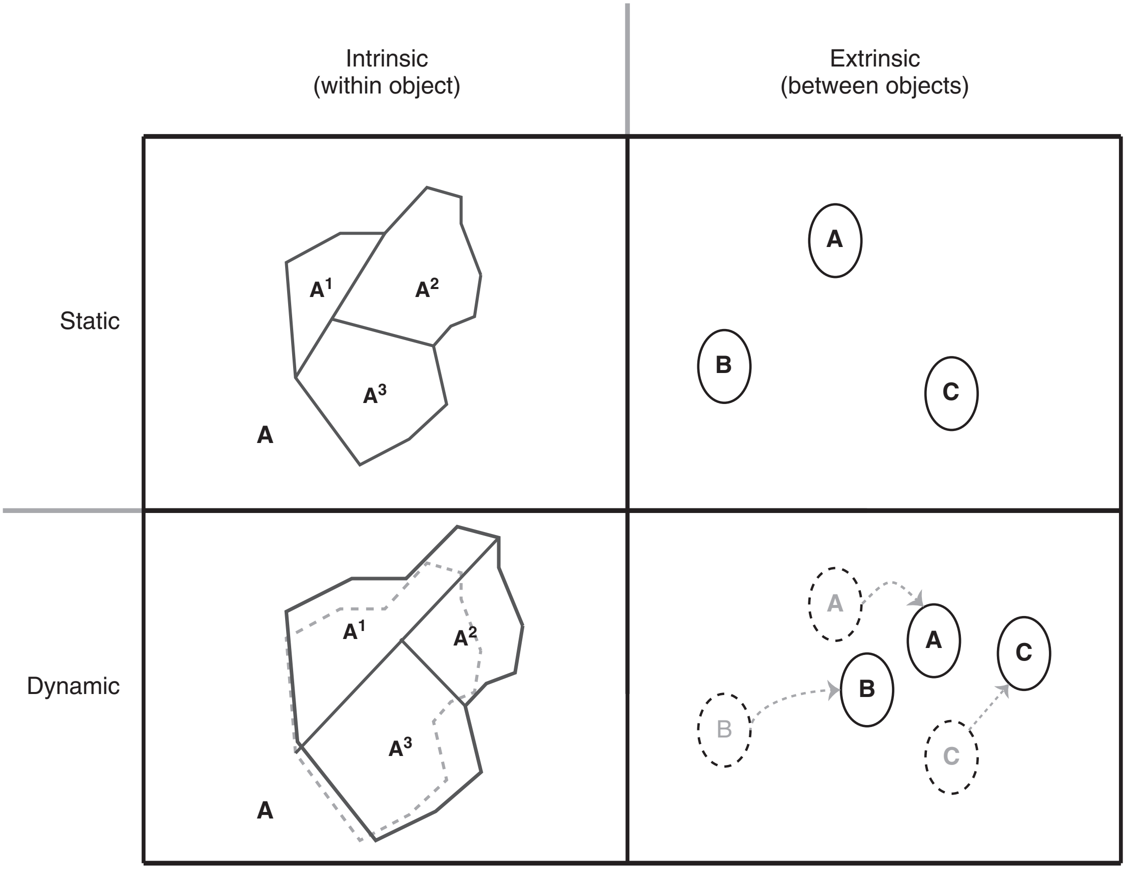

Figure 1 An organizing schema for spatial skills and concepts. Modified from Newcombe and Shipley (2014).

Divisions of size and scale

The term "scale" has several related but distinct meanings. As a noun, it refers to a particular range of sizes or magnitudes. In an adjective phrase, scale is often used to mean relative or absolute *size* on one such scale, for example "large-scale" or "human scale." The same entity may be considered large or small on different scales; even large ponds are small-scale water bodies.

When we say that each scientific, engineering, and artistic field is concerned with phenomena at some range of scales, we mean in some cases absolute size on the scale of all things, and in others the projective *psychological scales* of perception and representation (Montello 1993). Half a county can be viewed in the frame of an airplane window, and a two-dimensional projection of the entire Earth represented at a very small scale (a high ratio, or small representative fraction) to fit on a single sheet of paper. The "landscape" of a molecule can be scaled by a microscope to fill our field of vision.

There are disciplinary associations with particular scales, and disciplinary subdivisions can be scale-based. For example, distinct branches of physics concern phenomena at subatomic,

atomic, molecular, and astronomical scales. Chemistry concerns the dynamics of matter, principally at atomic and molecular scales. Industrial designers create tools and other mechanical devices at scales ranging from handheld objects to large vehicles. Architects design at the scale of buildings – single structures, ensembles of buildings, and the spaces within and between them. Many fine arts, including painting, sculpture, and dance, are intrinsically spatial, producing visual and/or kinetic forms; artistic scales in human terms can range from the *figural* (smaller than the human body) to *vista* (larger than the body but apprehended from a single location).

At the next larger scales we find geographers and planners, seeking scientific explanation and designing settlements and settlement systems in *environmental* space, which "is usually thought to require the integration of information over significant periods of time," and *geographical* space, which "cannot be apprehended directly through locomotion; rather it must be learned via symbolic representations such as maps or models … " (Montello 1993, 315).

Fundamental spatial concepts

Given that no universally accepted taxonomy of spatial concepts has been developed to date, much less a formal ontology, the following geographically oriented groupings are presented. Definitional statements have been synthesized from geographic textbooks and dictionaries.

Spatial primitives

The most basic of spatial concepts are studied in classical physics, topology, and mereology (part–whole relations). These are primitives in a sense, from which we derive more complex concepts and principles. As noted earlier, many primitive concepts are used metaphorically in reasoning about spatiality as well.

Objects (bodies) in the universe are constituted by *matter*, giving them *mass*. Objects thus have physical extension and time-indexed spatial location. They are *bounded* – that is, there is a division between object and not-object – and they may be *composed* of smaller objects or have features considered as *parts*. Objects are subject to external forces, including from gravitational fields, and can move in space. That is, they change position with respect to each other or to a reference point, according to laws first described by Isaac Newton.

The relative position of objects (and their abstract representations as points, lines, and areas) can be described in the primitive non-metric terms of topology. These include concepts of *containment* and *connection*. Relevant cognate terms include *adjacency* and *neighborhood*.

Location

Arguably, the most fundamental of spatial concepts for geographers is *location*, and like many spatial terms, its definition is problematic. The terms *location*, *position*, and *place* are often used interchangeably, along with *site* and *locale*. They are "near-synonyms," as each commonly appears in definitions of others. Each can be viewed as one kind of answer to the question, "where?" Geography seeks to explain the why of where, which requires first establishing location, as well as is practicable, by means of spatial descriptions. Geospatial data describe at minimum the location of some phenomenon and its class or category. As noted earlier, whereas all entities with spatial extent also have temporal extent, many geospatial data sets are either encompassed within a single temporal frame or divided into time-indexed "snapshots."

Geographic locations in this broad sense can be represented mathematically in the so-called absolute terms of coordinates on a grid of two to four dimensions (x,y [, z, t], where t is time) having an arbitrary origin, or in relative terms of *distance* and *orientation* (or *bearing*) related to other locations. Relative locations are also frequently described in topological or otherwise nonmetric terms, including vague natural language such as "just north of." Strictly speaking all locations are relative, whether to coordinates on an abstract grid and its possibly arbitrary origin, or to other entities. The reference origin of geographic coordinate systems is an estimated center of the Earth.

The *location*, *position*, *site*, or *locale* of a thing might be represented solely in mathematical terms or with additional attributes deemed essential to a particular investigator or perspective. For example, site and locale suggest important containment or environmental relationships.

In the most general terms, a place is a location about which we have something to say (Haggett 2001). However, the qualities of a place are understood by many geographers to include not only metrical location, but also (or alternatively) individual or collective human experiences there (Tuan 1977).

Distance

Euclidean distance is essential to metric descriptions of location and is thus a first-order concept one step removed from that primitive. Distances are the essential measure of spatial distributions (patterns), and therefore the basis for identification of *clusters*, *spatial association*, and *centrality*.

An important related concept for geographers, *cost distance*, is another example of the mutability of spatial concepts and their important value in reasoning more generally. Geographers have noted for many decades that metric distance is but one way of describing how far one thing is from another, effectively. The 12 miles between two locations across a plain and the 12 miles traversing a mountain have radically different meaning in human and economic terms of cost in physical effort and in elapsed time. Janelle (1968) developed the concept of *time–space convergence* to reflect the shrinking effect that transportation and communication technologies have upon the effective or functional distances of commerce and everyday life.

Representation

Our reasoning about spatial phenomena, and spatial concepts like their absolute or relative location, involves *representation* in several respects. When converting directly or remotely sensed data of counts and measurements into the mental, mathematical, physical, and graphical representations we call geographic information, we are reasoning about representations of concepts and not the phenomena themselves.

Two distinctive conceptual representations of space – those of objects and fields – inform representational strategies and methods. In simplest terms, the *object view* of space is that of "an inert container populated by objects" whereas the *field view* posits, "a 'plenum' characterized by a ubiquitous field" (Couclelis 1992, 70). These are analogous to a similar division in physics, and correspond to choices of vector and raster data formats in a GIS.

Several concepts pertaining to spatial representation derive from the object-field division and inform the digital *maps* geographers and cartographers make. We most commonly model physical objects geometrically in terms of *points*, *lines*, *areas*, and *volumes*. Fields are most often represented as matrices of uniformly sized rectangular cells corresponding to a particular spatial resolution, each with a single value for a given attribute. Fields can also be derived from point data by means of *spatial interpolation* and represented in vector form as, for example, triangulated irregular networks (TINs).

One of the most important representational techniques for viewing and analyzing spatial data involves the *overlay* of spatially aligned datasets in order to merge or compare them visually and computationally.

Pattern and process; form and function

A cornerstone activity of both physical and human geographers is the identification of patterns of *spatial distribution* and their explanation in terms of the underlying processes that produce them. An analogous activity, more particular perhaps to physical geography, is the description of spatial *form* and its explanation in terms of processes, function, or human purpose. Spatial patterns concern the extrinsic spatial relations between objects of interest, including events as commonly understood (e.g., crime or earthquakes). In contrast, spatial form concerns intrinsic properties of objects and entities considered as objects, including indistinctly bounded features of a larger object (e.g., a mountain and the Earth), or collections of component objects themselves (e.g., wells in an oil field, or streams in a watershed). This flexible and scale-dependent conception of objects means the division between form and pattern is not crisp, as we have seen in several imprecise classifications discussed already.

A number of fundamental spatial concepts are common to the discovery and description of form and patterns; some of these have been mentioned previously. The form of a geographic object or feature is described in terms of its *size* and *shape*, as delimited by its *boundary*, and by its *structure* – the number and arrangement of component *parts* or *features*. Many geographic phenomena have a *fractal* nature. That is, their structure is self-similar at any scale of observation. We see this when viewing higher and higher magnifications of crystals, for example. Clouds, river networks, and coastlines are said to have fractal qualities.

Patterns in the spatial distribution of geographic phenomena can be reified as the human-defined analytical objects, *regions* and *clusters*. The concept of region is normally defined as an *area* having one or more characteristics distinguishing it from surrounding areas; however, regions can be purely spatial (e.g., northern) and are not always geographic (e.g., anterior). The identification of particular geographic regions can be controversial because their defining criteria – characteristics considered and quantitative thresholds – are often subjective. Like objects, regions are bounded, although regional bounds are more often indistinct, or fuzzy.

Clusters are spatial *distributions* defined by an abnormal concentration (i.e., high *density*) of some phenomenon within a study area. Although clusters are often abstracted to aggregations of points, the phenomena can be large geographic features as well, such as a cluster of islands. Clusters may define regions: for example, Tornado Alley is an informally bounded region of the United States where tornados have historically occurred most frequently.

Spatial context

Observations of natural phenomena occur within a *reference frame*, which forms the context for their description and analysis. The concepts of scale and granularity are closely related to reference frames. For example, what constitutes a cluster at one scale and within a particular reference frame can appear as an even or random distribution in another. The well-known modifiable areal unit problem arises from the oftentimes arbitrary choice of bounds used for aggregating point data.

Objects of study – whether things or occurrences – are almost always impacted by their surroundings, that is, their *neighborhood*, *setting*, or *environment*. Elements of relevant spatial context can include adjacent and nearby things, network connections at any distance, the bounds of a study area, and areal divisions within it. All are important factors influencing the results and interpretations of scientific studies.

Tobler's "First Law of Geography" (1970) asserts that attributes of things that are near each other tend to be more similar than attributes of things that are far apart. Such similarity is assessed and confirmed by measures of *spatial dependence* and *spatial autocorrelation*. Because location and proximity are often omitted from statistical models, assumptions of independence for observational data are in many cases a fallacy.

Networks, connection, and interaction

Networks are the essential structural form of many human artifacts, from roads and railway systems to utilities infrastructure such as pipelines and power grids. Network structure appears throughout nature at many scales, for example in watersheds, circulatory systems, proteins, lightning, and neurons. Abstract network representations consisting of nodes and edges are an invaluable method of representing *connectivity* and *interaction* of all kinds. The analysis of social and professional networks has become a significant methodology in fields ranging from the history of science, to sociology, to business marketing. *Nodes* might correspond to individuals, groups, and publications or other products. *Edges* can correspond to friendship, co-authorship, affiliation, or production.

Spatial relations in all networks are at minimum topological ones of connectedness. If a network is geographically embedded, its nodes correspond to geographic locations. Its edges may as well, but with more or less resolution. That is, in some cases the geographical paths between nodes are either unknown or incidental. A common example of this is the representation of *flows*, where the attributes of interest are the source, target, class of substance, commodity, or activity and its aggregated magnitude for some period.

Many generalized spatial measures are relevant to all networks, whether geographically embedded and physical, or entirely abstract. These include size, density, connectedness, clustering coefficient, and node or edge centrality.

Spatial dynamics

Patterns of spatial distributions and of connectivity are intrinsically dynamic. They are the product of processes that transpire over time and their properties are time-dependent. The qualities, magnitude, and identity of many things in the world are in continual flux, and so a significant proportion of our scientific observations, measurements, and analyses seek to explain spatial change. Physical objects and Earth features change form, position, and orientation. Their identity can be changed by splitting and merging events, and by changes to essential attributes. A prime example is the changing shape, size, and nature of geographic features at the Earth's poles, as influenced by climate. These types of spatial change extend to non-physical geographic features such as cities and countries, as well as to regions, which can be defined by any number of physical and social variables.

Concepts involving the spatial dynamics of movement are relevant in many fields and at most scales. Many have precise meanings in physics and chemistry, and alternate but similar or metaphorical meanings in other fields. In physics, *diffusion* refers to a heat exchange process where a high concentration of a finite number of particles spreads throughout a solution in a random walk motion. In geography, diffusion can refer to the spread of a concept or practice from one or more locations to many more, but with some distinct differences: the paths taken by individuals are unlikely to be deemed random, and processes like *dispersion* and *migration* do not always entail some finite quantity dispersing elsewhere. Rather, geographic diffusion suggests probabilistic or deterministic dispersion and increasing magnitude. The term "flow" in the physical sciences refers to the continuous movement of matter (normally fluids) in a stream-like fashion. It is also used routinely and metaphorically in geography and many other fields in reference to nonmaterial things like ideas, and to nonfluids, such as commodities and currency in trade activity.

SEE ALSO: Geodesign; Ontology: theoretical perspectives; Place; Representation; Scale; Space; Spatial thinking, cognition, and learning; Spatiotemporal analysis; Topological relations

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