Thinking About Spatial Hierarchies

I am in Denver, and Denver is in Colorado, so I must also be in Colorado.

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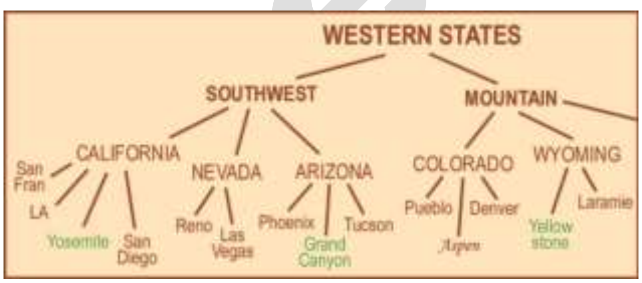
This chapter is about organizing and representing geographic information by noting where places fit into spatial hierarchies of various kinds. A spatial hierarchy consists of features, places, or areas of different sizes that can be mentally organized according to small-inside-large relationships. For example, a number of customers are part of the delivery route of a specific newspaper carrier. The routes of several carriers are inside the "territory" of a regional distributor. The distributor is inside the "coverage area" of the newspaper. Spatial hierarchies can (and usually are) multi-layered: a given area is usually part of a larger area and at the same time has smaller subareas within it.

A political map of the United States is a good example of a politically imposed spatial hierarchy: the 50 states are part of one large country, and at the same time each state is divided into smaller areas (counties, boroughs, or parishes). A governmental hierarchy is easy for students to understand, because individual areas at a given level of the hierarchy are usually both exclusive and exhaustive. Exclusive means that a given county is part of only one state. Exhaustive means that the small areas add up to fill the large area, with no overlaps or uncovered areas.

Spatial hierarchies, however, are not necessarily either exhaustive or exclusive. For example, a city might create enterprise zones within its borders. Within an enterprise zone, a company might get a tax break if they hire people with limited education or fluency in the local language. An enterprise zone is clearly a subordinate political entity within a city, but all together the enterprise zones seldom fill all the area within the city. Moreover, their boundaries may overlap with other politically imposed areas within the same city, such as school zones, police precincts, mail routes, or sewer districts.

Political organization of an area is a good example of a spatial hierarchy, but it is not the only kind. Natural environments have many examples of functional nestings of spatial areas. For example, the Tennessee River watershed has many small watersheds within it, and at the same time it is part of the larger Mississippi River system. The position of a place within that drainage hierarchy is very important in trying to deal with issues of water supply or pollution (Dollar et al. 2007).

There is considerable evidence that the human brain creates its "mental map" in the form of a rather small set of key landmarks and regions, which it uses as a framework for inserting additional details as needed. Those landmarks and details seem to be stored as a spatial hierarchy – details are remembered in terms of the major territory they are inside.



More than 30 years ago, people speculated that a person's mental map resembled an atlas of correlated maps at different scales that fit inside a larger framework based on a few landmarks or territories (Kuipers 1983). This model of the memory process closely resembles the structure of a GIS, with its collection of layers holding different kinds of information, all georeferenced to a common coordinate system. The difference is that a pre-defined metrical grid is the dominant organizing theme in the GIS, whereas the mental hierarchy of a person is based on a more haphazard collection of landmarks and areas. For that reason, it may have geometric distortions. Indeed, several people have devised ingenious experiments to assess the amount and direction of distortion.

Research on Thinking About Spatial Hierarchies

Many independent research studies point to the same conclusion – each person appears to have a mental hierarchy of locations in which individual places seem to be organized into territories around a few major landmarks. This kind of research began by testing some fairly simple hypotheses. Studies in the 1980s, for example, suggested that the human cognitive map might have an asymmetrical organization, a kind of one-way dominance relationship, because a person's estimate of distance from a major landmark to a minor object seems to be consistently longer than when the person is asked to estimate the distance from the minor object to the major landmark (Sadalla et al. 1980). Another study from later in the same decade demonstrated that humans find it significantly easier to remember objects that are close to major landmarks (McNamara et al. 1989). Another decade later, studies refined those statements by showing that distances are remembered in a "temporally non-symmetric" way: distances seem smaller when the location of a landmark is fixed in memory first, and as larger when other features are fixed first (Newcombe et al. 1999).

These early studies have one thing in common – they all provided a pre-selected set of landmarks for the individuals participating in the study. As a result, the studies are somewhat unrealistic, because in the real world "people are not passive observers; they bring to bear conceptual knowledge and encoding strategies that are used to select landmarks" (Bryant and Subbiah 1994, p. 136; for more detailed explorations of scale relationships, see Greenauer and Waller, 2010; Han and Becker, 2014).

This conclusion about the importance of hierarchical relationships has many implications for people who are designing maps or teaching geography. Most of the implications stem from the fact that different students may have different mental maps of a given area, with different kinds of spatial distortion, depending on which landmarks they chose (or were given) as the initial basis for their organizing hierarchy. This observation, in turn, is a strong argument in favor of a curriculum that explicitly teaches a small set of especially important geographic features at a fairly young age, so that all students in a class are primed to include at least some of the same landmarks in their mental hierarchies of large areas and small places within them (see activity folder).

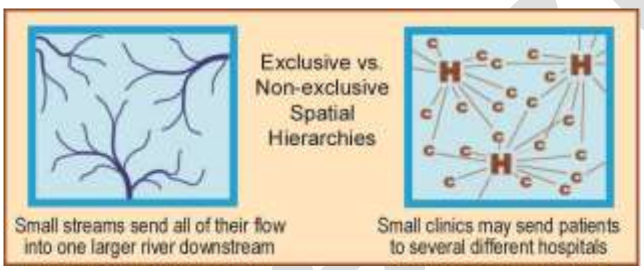
Another problem is that the process of communicating the locations of key landmarks inevitably has to use terms that are already available in the language of the students. Confusion can occur in a multi-language classroom, for example, because different languages have different words for dividing space. English, for example, has two basic demonstrative words to indicate distance from a speaker – *here* and *there*. By contrast, "a Spanish speaker refers to something here as *aquí* and . . . something that is "in this general area" or "near here" as *ahí* and something "over there" as *allá*" (Milson 2007; see also Regier and Carlson 2001; Egenhofer and Sharriff 1998). To make matters even more complicated, the prepositions of movement (e.g., *into, through, beyond,* etc.) appear to be stored and processed in a different part of the brain than the prepositions of status (*inside, next to, between* – A. Chatterjee, personal communication, May 2008). In fact, some languages (e.g., German) incorporate that fact into the case endings of associated verbs or nouns. Because the uses of these prepositions are physically located in different places in the brain, they tend to be linked in different ways with visual memories and verbal phrases. This complicates the task of assessing whether different students actually have stored their memories of specific landmarks in similar ways.

We should note here that we are emphatically not expressing our agreement with a seductive idea that you occasionally hear in late-night discussions among college philosophy majors, namely that that linguistic differences among humans are so profound that no "error-free" communication between individuals is possible. That particular conclusion seems to be routinely refuted by the simple fact that people can give each other directions to a meeting place and reasonably expect to find each other when they get there! At the same time, we do suggest that it is naïve to assume that the languages and other prior knowledge of different students have no effect on their geographical understanding, even for the basic task of establishing a hierarchical framework. In fact, to the extent that teachers assume a lack of language effects, they are unlikely to pay due attention to the process of communication, and therefore they may not recognize those differences when they occur. Lynn Liben has provided an especially cogent anecdotal observation of one “small” misunderstanding of this kind, in her discussion of several attempts to overcome some children’s misconceptions about the meaning of the term “north” (Liben 2006, pp 235-236).

As noted above, the hierarchical organization of space around a few key features is especially important in human wayfinding, i.e. at the scale of an individual navigating through space (Jansen-Osmann and Fuchs, 2006; Wang and Brockmole, 2003). That kind of “personal-scale” spatial thinking is obviously important, and it is understandably the subject of a great deal of research, but it is not our primary focus in these essays. It seems clear, however, that at least some of the basic principles of person-scale wayfinding also apply to spatial thinking at geographic scales, when people are looking at maps or other spatial representations.

One task of a teacher, therefore, is to ensure that students fully comprehend the position of a given map in a spatial hierarchy of sizes, from blocks through communities and countries to continents. Fortunately, a number of standalone and web-based mapping programs have “zoom” controls that allow relatively easy changes of scale. A teacher can use these to diagnose how well students understand that the features that can be seen in a place depend, at least in part, on the scale at which the place is viewed.

The other major educational challenge is to get students to appreciate that a particular place can simultaneously “belong” to a number of different spatial hierarchies, as well as to different layers within a single hierarchy. Some hierarchies (like political regions or watersheds) have clearly defined borders around individual sub-parts. Others (like medical services) are more loosely organized, with neighborhood clinics that might send patients to several different hospitals or specialty centers in the next level up the hierarchy.



To build a solid foundation for understanding spatial hierarchies, primary-school students need to learn that they can be inside a neighborhood, city, county, state, and country, all at the same time – “My community is part of Chicago; Chicago is in Cook County, so I am also in Cook County; Cook County is inside Illinois, so I am also inside Illinois; etc.” (Adults, of course, are all too aware that they have to pay taxes to a city, county, state, and country!). This concept of nested areas must be quite clear before someone can wrestle with the more ambiguous and overlapping spatial hierarchies of wildlife ranges, shopping centers, medical facilities, or professional sports. Those hierarchies, however, are far more important in both nature and the economy – it is difficult to see how we can solve problems of pollution, housing, medicare, or stock market bubbles without understanding the spatial hierarchies that help to channel the flow of water, care, and money!

[student activities: inside and outside in the K-2 folder; river hierarchies in South Asia]

Sample dialogs from two teachers trying to teach about transactions in an economic hierarchy

T: Today we are going to look at economic multipliers – that's economics-talk for the fact that whenever someone spends a dollar in some local place, it often produces more than a dollar of economic activity in the larger area.

Here is a simple example. Suppose I pay you ten dollars to mow my lawn. You spend one dollar to buy some candy in a store and another dollar to buy a something to drink from a machine. The total economic activity is now twelve dollars. That's a multiplier of 1.2 – my ten dollars eventually led to 12 dollars of exchange among people in the community.

T: Can anyone think of another example? S: a teacher spends some of her salary on rent

T: good. any others? S: A store owner spends some of the income paying for electricity

T: OK. What's the general principle here?

S: every time you spend some of your money, it creates some more economic activity, so if people buy a lot of things from each other, there is a lot of activity

T: Today's topic is economic multipliers. Suppose I pay you ten dollars to mow the lawn, and you spend one dollar for something to drink. That's eleven dollars of total economic activity. But how did that bottle get to the store?

S: a truck delivered it

T: so the store owner had to pay the truck driver, right? Where did that money come from?
S: from what we pay the store owner?

T: OK Now, the truck driver goes to stores all over the city, right? S: I suppose . . .

T: so one truck driver collects money from many stores. Does any money go from the truck driver to a local community? S: well, they might buy gas, or some coffee in the store

T: Good! AND, . . . truck drivers and store owners all over the state pay taxes to the state government, which pays some of that back to me as a teacher.

T: That's how money moves up and down a kind of geographic hierarchy, from local community to state capital and back

These dialogs highlight some differences between a lesson that reinforces a specific mode of spatial thinking and one that does not. The difference is often quite subtle, but it also is usually quite pervasive – in short, "the devil is in the details," and the details are cumulative

The two dialogs are the same length (170 words), but the second dialog introduces the idea of a spatial hierarchy and thus helps explain how complicated a system of exchange can get. The first dialog provided several examples, but they are all restricted to one level in an economic hierarchy – individuals meeting each other face-to-face in a local community and paying for goods or services. These transactions are very important, but they are a dangerously incomplete picture of the economy.

Ideally, a teacher would shift back and forth between these perspectives, helping students generate additional examples of both peer-level and hierarchical transactions in the economy. Geography provides a particularly good way of doing both, especially if a lesson has a primary focus on one mode of spatial thinking but makes reference to others as appropriate.

Additional student activities that involve thinking about spatial hierarchies

A. Describing all of my "insides"

Everyone agrees that young children should memorize their address and telephone number, in order to be prepared in an emergency. This desirable goal can be turned into a geography lesson.

1. Modify the form in the folder so that it fits the local conditions (e.g. by substituting house and road for apartment and block if your school is in a rural area)
2. Have each student work through the list of insides – my apartment is inside of a building numbered 8300, my building is inside a block called Talbot Street, Talbot Street is inside a neighborhood called Kew Gardens, my neighborhood is inside a borough called Queens, my borough is inside New York, my city is inside a state also called New York, my state is inside the United States, so I am also inside the United States, etc. . . .

Follow this with maps that show other insides, like Houston is inside a state called Texas, etc.

B. Tracing a drop of water on its way to the ocean (or wherever the last river ends)

Find a number of maps of different scales that cover the local area. Adapt the instructions to fit the local area (if your school is right next to the ocean, much of this may be impossible!)

1. Find a map that shows small creeks, and put a dot or sticker on it to show the location of the school (or other site of interest, such as a factory, playground, or waste treatment plant).
2. Identify the creek that water from the site is most likely to flow into.
3. Trace that creek (perhaps on another map with a broader scale), and identify what river it flows into. (Optional: trace that river upstream to see where it comes from).
4. Follow that bigger river and identify what even-larger body of water it drains into.
5. Repeat as needed to establish the entire drainage hierarchy.

C. Tracing a store product back to its source.

1. Pick a common product sold by a merchant who is willing to cooperate (see caution below).
2. Have students interview the merchant, in order to find out who delivers that product, and where their warehouse is located. Locate that on a map and draw a line to the store.
3. Continue by asking where the warehouse might get the product. Add to the map.
4. If the merchant is willing to describe the process, ask for information about other stores and communities served by the same warehouse or distributor. Add that information to the map.

CAUTION: Some local merchants are delighted to cooperate and can make this a memorable and interesting activity. Others view it as a bother and do it very reluctantly. It pays to ask first!

D. Describing the hierarchy of a professional sports team.

1. Pick a team (or several) that might have fans in your community.
2. Have students do web research to identify where that team has its AAA, AA, A and rookie minor league teams.
3. Draw lines on a map connecting those farm-team cities to the city where the major-league team has its stadium.

CAUTION: This is a superb example of a non-nested (overlapping) spatial hierarchy – unlike the warehouse that provides goods to a group of stores in a specific area, a given team seldom has its minor-league affiliates in the same part of the country. That is not a bad message to learn – that spatial hierarchies do not have to be simple enclosures. To make this activity even more useful as (yet another) way to reinforce basic placenames, have students identify the nearest major airport and the states that a player would fly over if called up from the farm team to the major league.

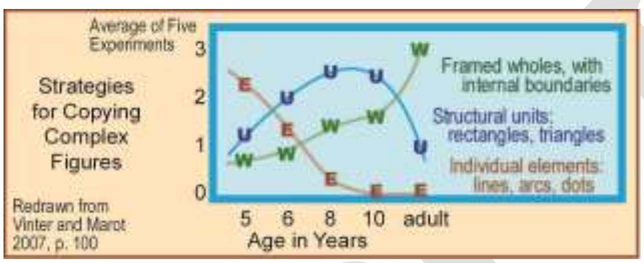
E. Describing the hierarchy of a business.

1. Choose a Fortune-500 company or a major international corporation.
2. Use the web to find where the company has branch offices or factories; locate on map and draw lines to connect to the head office.

Detailed Review of Research on the Process of Thinking about Spatial Hierarchies

Two studies from the late 1970s illustrate the kinds of evidence that led researchers to conclude that human beings tended to interpret at least some spatial relationships in terms of a hierarchy of sizes. In one widely cited study, people were asked whether Reno, Nevada, was located west or east of Los Angeles, California. Their answers suggested that mentally putting Reno into a spatial hierarchy as a city inside the state of Nevada made it difficult for people to think of the correct answer (west), because the most of Nevada is indeed generally east of California, and therefore people seemed to think that any places within Nevada must also be east of any place in California (Stevens and Coupe 1978; for other variations on this idea, see Baird 1979; Hirtle and Jonides 1985, Friedman et al. 2002, Burris and Branscombe 2005; Friedman et al. 2012).

By the mid-1990s, people were writing articles entitled “Further evidence for the hierarchical representation of spatial information” and claiming that “a true hierarchy is multi-leveled, with clusters within clusters” (Holding 1994 p 138). At roughly the same time, developmental psychologists began conducting experiments to figure out when and how children begin to use hierarchical ideas in communicating about spatial relations. One answer is that primary school children can interpret directions that go from large-scale structure to local details, but their descriptions of places are more likely to begin with specific details and then go up the hierarchy to general structure (Plumert et al. 1995; 2001; see also Sandberg et al. 1996; Dukette and Stiles 2001; for a recent review, see Poirel et al. 2006, 2008). This is most obvious in looking at strategies for copying a complex figure; young children tend to focus on small elements, while older children and adults are more likely to begin at higher levels in the organizational hierarchy (Vinter 2007; for a look at changes that occur later, see Huizinga et al. 2010).



Meanwhile, other researchers were:

- exploring hierarchical notions of direction rather than size (Papadias and Egenhofer 1997);
- making a general review of the role of hierarchies in memory (Mishkin et al. 1997);
- applying the idea of hierarchy to visual object recognition (Riesenhuber and Poggio 1999);
- exploring the possible competition between grouping and hierarchical organization (Han et al. 1999)
- examining the role of object attributes such as color in promoting a hierarchical as well as regional classification of space (Hommel et al. 2000);
- exploring how these hierarchical structures seem to be “tuned” to perform many kinds of hierarchical analysis at different scales (“octaves” - Deco and Heinke 2007);
- examining the neural substrates of various kinds of hierarchical thinking – a process that is complicated by the fact that there do seem to be various kinds! (Han et al. 2004; Qin and Han 2007; Neunuebel at al. 2013).
- looking still more closely at how brains fit various levels of a hierarchy together (Greenauer and Waller 2010; Conci et al. 2011; Zhang et al. 2014)

Fast-forward through another ten years of research, and there now seems to be a consensus about the analytical importance of spatial hierarchies in tasks that range across a wide scale continuum, from remembering the names of countries in a continent to dividing words into syllables (Chokor 2003; Vinckier et al. 2007). The latter study is one of many that tried to identify the brain regions that seem to be doing this kind of hierarchical analysis: "the left occipitotemporal visual wordform area, far from being a homogeneous structure, presents a high degree of functional and spatial hierarchical organization" (Vinckier et al. 2007, p 143).

Meanwhile, people in many other disciplines were emphasizing the role of spatial hierarchies as an important part of their explanatory frameworks. This process started in disciplines that deal with human-imposed hierarchies, such as political science and management economics (for an early example, see Westaway 1974). In recent years, more complex studies of hierarchical patterns have become commonplace in many fields of natural science, from atmospheric dynamics to wildlife biology (e.g., Wu and David 2002). Another study of the same general topic provides a succinct summary statement:

> "Within beds of blue mussel (Mytilus edulis L), individuals are aggregated into small patches, which in turn are incorporated into bigger patches, revealing a complex hierarchy of spatial structure. . . . the fractal analysis detects the multiple scaling of regions even when the spatial structure may not be distinguished significantly by conventional statistical inference" (Kostylev and Erlandsson 2001, p 497).

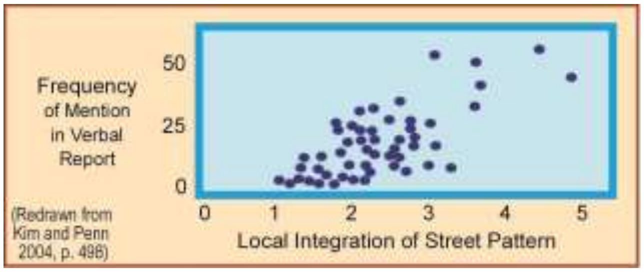
The availability of a GIS with sophisticated spatial analysis tools has definitely aided these investigations. As one team of urban geographers concluded, "Using GIS to display energy flows in a spatial context, the distribution of the six energetic zones can reveal the spatial energetic hierarchy within Taipei metropolis" (Huang et al. 2001). GIS-based hierarchical models have also become important in political science (Eagleson et al. 2000) and in public health and epidemiology (Grenfell et al. 2001; Vibaud et al. 2006).

Architects and urban planners, meanwhile, take the idea of a spatial hierarchy and apply it in the design of large buildings or planned urban neighborhoods. A large number of investigators have looked at ways to design these built environments in ways that maintain visual interest and at the same time help people navigate through the spaces and find places within them. Some key findings include:

- Adults tend to prefer overall building structure over local landmarks (Stankiewicz and Kalia 2007).
- Children tend to focus on local landmarks but can be trained to look for more distant ones that are higher on the visibility hierarchy (Cornell et al. 1994).
- Instructing people to focus on overall route structure can improve memory without reducing recall of local landmarks (Van Asseln et al. 2006).
- The brain seems to process landmarks at different levels in the hierarchy in different areas of the cortex (Renaudineau et al. 2007; Szczepanski and Kastner, 2013).
- Mental processing times are shorter for instructions about major landmarks as opposed to local streets (Tom and Denis 2004).

- Some promising studies, however, can have their findings compromised by inferior design of the experimental map (Rossano and Hodgson 1994).

The notion of the "legibility" of a building or street network is a common thread (and useful Internet-search keyword) in these studies. A legible environment is defined as one in which the overall hierarchical structure of the space can be reasonably understood by a careful reading of its local properties (Bafna 2003). Studies have shown that people remember features better when they are located on streets that have a well-integrated, easy-to-understand hierarchical pattern (Kim and Penn 2004).



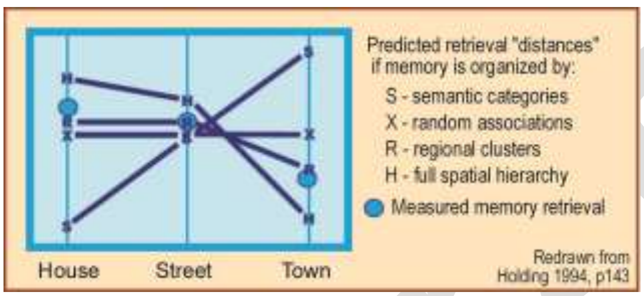
Some investigators have looked at how an "illegible" building can lead to persistent confusion, which they attribute to inadequacies in the "integration of nested representations" (Moeser 1988). Others tried to identify the characteristics that helped make a building more legible (Abu-Gazzeh 1996). A handful of investigators have extended this form of applied work to examine the nature of spatial hierarchies formed by people who do not have full mobility, visual acuity, or other sensory input (e.g., Noordzij et al. 2006).

Finally, notions of hierarchical spatial organization are also important in designing virtual environments and mobile robots (for a few relatively accessible representative examples of what is a fairly large but often quite hard-to-find body of research, see Kuipers 2000; Steck and Mallot 2000; Vasudevan et al. 2007).

Distinguishing between thinking about spatial hierarchies and other modes of spatial thinking

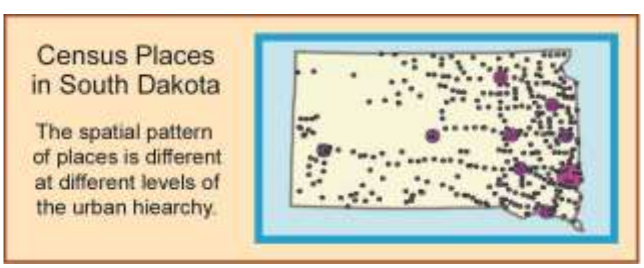
One significant overlap is between the concepts of spatial regions and spatial hierarchies. Indeed, many geographers' explanations of the concept of region include the idea of hierarchy, by noting that a given region often has subregions within it. In this worldview, the longleaf pine forest of the Coastal Plain and the loblolly pine forest of the Piedmont are subregions within a larger region of pine forests in the southeastern United States (for other "official" ways of organizing those pine subregions into larger regions, see USDA 1981; Gallant et al. 1989).

As noted in the chapter on regionalization, we think that there are both logical and neurological reasons to distinguish between regionalization (which is basically a horizontal division of space into separate areas) and the formation of spatial hierarchies (which usually are like vertical nestings of smaller areas within larger ones). Subsuming both ideas under a single expanded definition of region simply transfers the hard work to another level of the idea taxonomy. Moreover, it fails to recognize that the human brain seems to use structures on the side of the head for thinking about hierarchies, whereas areas closer to the back of the head are more prominently engaged when people are thinking about regional divisions. The picture is not entirely clear, however. A handful of mid-1990s studies of memory organization tried to draw a clear distinction between hierarchical and regional structures. They made predictions of how memory would perform if it were organized in specific ways, but their empirical experiments seemed to show that actual memory performance falls in the gap between what is predicted by hierarchical and regional models (Holding 1994).



Those studies should be replicated now that we have access to scanning equipment that can monitor brain processes while people are dealing with spatial questions. In the meantime, we think there already is ample evidence to support the suggestion that geographers would be better off to make a distinction between regional and hierarchical spatial thinking at the highest level in our taxonomy of spatial-thinking ideas. If that conclusion, in turn, adds one more reason why we should abandon, or at least modify, the famous "five themes," so be it. We think there are plenty of good reasons why that 20th-century formulation of geography's activity should be expanded to reflect what neuroscientists know and geographers actually do in the 21st century.

Another source of potential confusion is between the ideas of spatial hierarchies and spatial patterns. This logical overlap occurs because a map can easily have several different kinds of patterns at different scales. For example, look at the map of census places in a state like South Dakota.



The pattern of population has an obvious imbalance at a state scale, with more than 80 percent of the people living in the eastern half of the state (a reflection of the higher productivity of farms in the rainier part of the state). The imbalance would be even more striking if the state did not have a medium-scale cluster of population around the Black Hills, with their forest and mineral resources. A still closer look at the population map shows a clear east-west alignment of small towns, which were founded at intervals along the railroads that stretched westward across the plains. Finally, there is a micro-scale clustering of people near county seats and transportation junctions, and an even smaller pattern of aligned houses along streets in small communities (for a parallel look at scale effects in the visual processing of object shape, see Jolicoeur 1987).

In short, the spatial patterns of population seems to respond to different causal influences at different scales – rainfall at a state scale, topography at a medium scale, railroad alignment at a county scale, and road patterns at a local scale. Those differences correspond roughly to a political/administrative hierarchy that goes from state to region, county, and town. A complicated, multi-causal spatial pattern such as population, however, is logically different from a "pure" spatial hierarchy, in which a single cause (governmental jurisdiction) produces a functional nesting of areas.

South Dakota can also serve as an example of another potential overlap between modes of spatial thinking, between the concepts of spatial hierarchy and spatial aura. The state has a number of distribution and collection hierarchies, including the Postal Service, the companies that run big-box retail stores, and the grain-marketing services that gather wheat from many counties and transport it to ocean ports for export to other countries. These activities are aspects of what has been described as "geography's finest intellectual product" – central place theory (for a concise review, describing central place theory as the example of the use of spatial thinking in geography, and ending with that quotation, see NRC 2006, pp. 88-93).

The logical overlap occurs because a given farmhouse can be described as being within the spatial aura (zone of influence) of a particular town where people usually go for daily needs, such as school, shopping for things like gasoline and milk, etc. That town, in turn, can also be seen as being within the larger zone of influence of a regional center such as Sioux Falls, where people go for medical services, entertainment, or specialized stores for books, music, fashionable clothing, and other products that are unavailable in the local town. Sioux Falls, in turn, is generally seen as part of the "territory" of companies, hospitals, and sports teams in Minneapolis, the nearest large urban area. In effect, just as large political areas can (and usually do) have smaller political subareas within them, big places with big commercial auras can have smaller places with smaller auras within them.

In short, spatial thinking uses different modes, with different brain structures, to describe the same phenomena from different analytical perspectives. Like the different muscles of their arms (an analogy we find particularly useful in teacher workshops), people usually use different modes of spatial thinking *in different combinations* in order to solve particular problems. That cooperative use, however, requires roughly similar levels of competence in each mode of spatial thinking. For that reason, it is important for students to "exercise" their hierarchical-thinking skills as well as the skills of comparison, regionalization, pattern recognition, feature association, and so forth.

Issues with using a GIS to support thinking about spatial hierarchies

The famous point-in-polygon problem is the main issue with using a GIS to help people think about spatial hierarchies. Here is a brief summary of the problem, in a simple comparison:

1. It is easy for both the human eye and a computer to decide whether a point is inside of an area like Wyoming, which extends from (roughly!) 104 degrees of longitude to 111 degrees west, and 41 degrees of latitude to 45 degrees north. A programmer simply has to write a set of "if-then" statements like "if latitude of point X is greater than base latitude L of polygon P, and if . . . , then point X is inside polygon P."
2. It is somewhat harder to tell a computer how to decide whether a point is inside of an area that is not a simple mathematical shape, like a rectangle or circle. For example, consider the mathematical complexity of trying to "train" a computer to recognize what the human eye can see quite easily, namely that point P is indeed inside of Congressional District 4 in western Chicago (see also the CD unit on Pulaski Road)?

[insert Fig 9-8 here]

The issue becomes a problem when we introduce some uncertainty into the system. For example, if a map of oil wells adheres to National Map Accuracy Standards, the location of an individual oil well can still be off by a tenth of an inch at the printed scale of the map. When that map is digitized and overlaid on a map of, say, property ownership, it is possible that the oil well will mathematically appear to be outside of a landholding that it is actually inside of in the real world.

This book is not the place to review all of the research that has been done to address the point-in-polygon issue (and, for most practical purposes, to solve it with a reasonable degree of speed and accuracy). The point that we wish to make is that the mathematical complexity of the point-in-polygon problem in some landscapes is one reason why a fully functional GIS is likely to remain somewhat complex, especially if the user is trying to enter completely new data into the system. It also can make it easier to understand why the cost of entering data into the system can sometimes seem so high. That combination of complexity and cost, in turn, helps explain why users with specific questions often find that a GIS seems to lack the particular kinds of data that are needed to solve their particular problem.

As noted above, the point-in-polygon problem is the underlying reason why people often encounter problems when they try to combine different data sets with different degrees of inherent accuracy. One data set, for example, might have an "acceptable" error in specifying the location of a particular point, such as an oil well. That error, however, may still be so large that the point appears to be outside of a specific area in another data set, when in fact the point is actually within the area for the purposes of a potentially very significant spatial hierarchy, such as a municipal boundary or other area with taxing authority. The only solution for this mismatch is a careful reading of the metadata for each data set, coupled with a realization that the likelihood of problems like this tends to be greater in geographical landscapes that are more complicated.

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