Thinking About Spatial Sequences and Transitions

You didn't tell me I'd have to climb over a mountain to get here!

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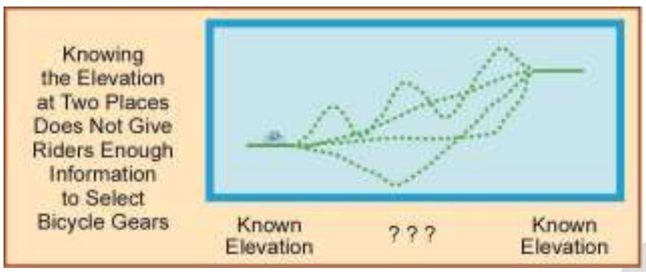
If two places have different conditions, then there has to be a change of some kind in the "area of transition" between the two places. This deceptively simple and obvious statement is actually the basis for a whole category of thinking, one of several logically and neurologically distinct modes of spatial reasoning.

For a simple illustration of the idea of spatial transitions, one that works well in a middle-school classroom, imagine that you are in a bicycle race. The race guide says that you are riding at an elevation of 500 feet above sea level, and that a hilltop one mile ahead has an elevation of 1000 feet. With this information, you have a clear understanding of the altitude at each place. That knowledge of conditions is useful information, but it is not enough. You cannot select an appropriate bicycle gear until you know the nature of the transition between the places. Is it a steady uphill climb? Or is it a level stretch followed by a sudden steep slope? Or is there a higher hill or deeper valley in between, or a series of ups and downs?



This essay will explore some of the ways in which people conceptualize and communicate about spatial transitions. Teachers may notice some links with mathematics education, because people often use line or bar graphs to show spatial transitions. A side profile, for example, is a common way to show the change in elevation from one place to another. Profile-like graphs, however, can have many other applications. For example, they can be used for topics as varied as rainfall, crop productivity, house age, family income, or Republican vote.

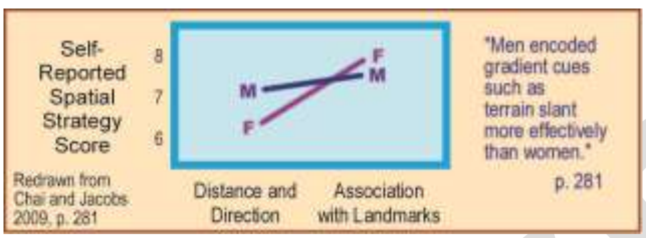
For many millennia of human history, the only true window we had into the workings of the human brain were animal experiments, behavioral studies, and the kind of "research" that is grouped together under the term "lesion studies" – studies of people who had strokes, accidents, or injuries that damaged specific parts of the brain. The design of a lesion study is simple:

1) find a person who survived a stroke, battlefield wound, or industrial accident,
2) measure what parts of the brain were damaged, and then
3) give some tests to identify what kinds of "thinking" the person is still able to do.

The biggest problem with lesion studies is an ethical one – you have to take the subjects "as is," because it is ethically unacceptable to inflict deliberate damage to a specific part of someone's brain, in order to observe what skills or memories are lost as a result of the damage.

Then, in the late 1990s, PET and fMRI brain scans made it possible to observe "intact" human brains as people performed some kind of activity, such as estimating the length of a line or deciding whether a rotated shape was actually the same as an unrotated example. These studies seemed to suggest that the human brain has some specific structures that help in encoding and storing information about spatial sequences, the order in which features are encountered during real, simulated, or imaginary movement through space (Chiba et al. 1997; Ghaem et al. 1997; Beiser and Houk 1998; Fortin et al. 2002). This passive-scanner-based evidence for localized brain activity was strongly reinforced in 2006, when researchers used a completely independent technology to show how a memory for a spatial sequence can be disrupted by application of a transcranial magnetic pulse to a specific part of the frontal lobe of the brain (Histed and Miller 2006). Several independent technologies thus point to the same conclusion: a few small areas in the frontal lobe, roughly above and behind the left eyebrow, are engaged when we remember scenes or conditions in their proper spatial sequence. These sequence-memories can be examined, either verbally or mathematically, in order to describe the change that occurs as we proceed along a route of some kind (either in person, on a video screen, or just by moving our eyes across a map).

Thinking about transitions can be done with any kind of sequential memory – spatial, temporal, verbal, kinesthetic, even musical. In recent years, however, researchers have demonstrated that the processing of spatial-sequential information is more fundamental and complex than initially thought. Some of the complexity emerges as a consequence of the spatial organization of brain regions and the links between them (Gevers et al. 2004). Some researchers have even postulated that the brain has a completely parallel system of location-encoding that relies on summaries of sequential information as its organizing theme. This *parallel map theory* suggests that the brain more-or-less automatically encodes information about gradients (local slopes or other changes in conditions) as well as landmark and route information. Those gradients can involve a number of different kinds of conditions, including elevation, noise, crowdedness, or brightness (Jacobs and Schenk 2003; Kelly 2011). Moreover, the use of gradient information may be one of the major ways in which males and females differ in their spatial thinking (Chai and Jacobs 2009).



Research on Spatial Sequences, Gradients, and Transitions

As noted several times, the human brain appears to form several different spatial representations at the same time, although we may be consciously aware of only one at any given moment. In this essay, we are looking specifically at representations that seem to involve some kind of gradient or spatial transition from one place to another. The parallel map theory (the idea that we simultaneously form a gradient map as well as a more conventional mental map of objects) is especially attractive because it helps explain some observations that were made a long time ago.

One famous example is the celebrated balloon-and-yoyo "experiment" of the 1970s. In those studies, people took less time to answer if they were asked to specify which of two balloons was *higher* than if they were asked which balloon was *lower*. The reaction time was apparently influenced by the directional gradient that correlates with the "natural" tendency of a balloon to rise. When the [imaginary!] balloons in the first experiment were replaced by imaginary yoyos, the reaction-time difference was reversed – people took less time to decide when they were asked which yoyo was lower than if they were asked which yoyo was higher (Banks et al. 1975).

These findings, in turn, were seen as confirmation of even earlier speculation about what was called the "semantic marking of spatial dimensions." Semantic marking starts with the mental assignment of one direction as the expected, "normal," or "good" direction. That assignment is followed by a tendency to conceive of the opposite direction only in terms of its opposing relationship (Clark 1969). Thus, in the case of the balloons, "up" is the expected direction, and "down" is the direction that the brain somehow marks as "not-up."

While behavioral psychologists were theorizing about possible reasons for semantic marking, some researchers in other disciplines had independently explored the relationships between mental "measurement" and mathematical graphs. These studies suggested that people intuitively associated the slope of a line with rate of change, even in the absence of formal schooling. Again, the idea that people automatically encode gradient information would provide at least a partial explanation for these findings (Gattis and Holyoak 1996; see also Tversky 2001).

Finally, the popular idea that students can be categorized according to "learning style" can be seen as a somewhat independent line of evidence that fits with the parallel map theory. Two best-selling books played important roles in stimulating these discussions: *Drawing on the Right Side of the Brain* (Edwards 1979) and *Frames of Mind: The Theory of Multiple Intelligences* (Gardner 1983). One notion that many readers got from these books is the simple idea that people fit into two primary categories – left-brained people who are presumed to be verbalizers, and right-brained people who are more likely to prefer visual means of communication.

In teacher workshops, we often describe this notion as "like, soooo 20th century," because the idea was popular in the late 1900s but has always had an awkward empirical problem. When confronted with a task that involved the interpretation of a side profile, line graph, or other representation of change from one place to another, the average performance of so-called visualizers was rarely significantly different from that of people who scored high on tests that were designed to identify verbalizers.

This dilemma was neatly resolved early in the 21st century, when a series of studies rather conclusively demonstrated the existence of several kinds of visualizers. When shown a graph or other visual representation, some people apparently perceive the graph as a snapshot of a scene, while others seem to see it as a summary of a gradient (Kozhevnikov et al. 2002; 2010). In effect, some people seem to see a graph line as a spatial pattern or a visual image of the edge of a region (using mainly the visual areas in the back part of their brains), while others visualize it as a summary of a spatial transition between endpoints (and thus also engage the mathematical-comparison areas and the recently-discovered sequencing area in the front of their brains).

Identification of these seemingly unconscious tendencies helped explain the earlier failure to observe differences in performance between so-called visualizers and verbalizers. In effect, the old category of "visualizers" contains [at least] two distinct groups. People in one subset of visualizers consistently score higher than verbalizers on graph-interpretation tests, while those in the other subset usually score lower. The average score when the two groups of visualizers are lumped together, therefore, is not different from that of the verbalizer group.

Percentage with specific combinations of scores on spatial-ability tests and visualizer-verbalizer scales

		verbalizer	visualizer
spatial score	High	15	41
	Med	64	22
	Low	21	37
Average spatial score		1.94	2.04

Redrawn from Kozhevnikov et al. 2002, p. 56

Another group of studies has added yet another dimension of complexity to our ideas about the perception, storage, and retrieval of memories of spatial sequences. In one study, for example, people were asked to solve a wire puzzle that involved performing a sequence of specific motions. Music played in the left ear interfered with the speed and accuracy of people using their left hands, but not their right hands. Playing music in the right ear, by contrast, interfered with the use of the right hand (McFarland and Kennison 1988). At the very least, this study suggests that the brain has two separate pathways that link retrieval of spatial-sequential knowledge with intentional hand movements.

This finding is only the tip of the complexity iceberg, however. Several studies suggest that the brain has independent mechanisms for encoding spatial and non-spatial sequences (Mayr 1996; Tubau and

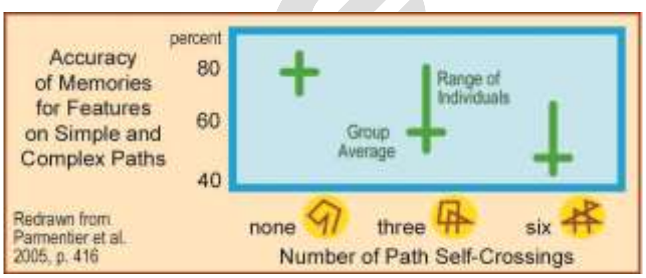
Lopez-Moliner 2004). Another group of studies show that people can remember a spatial sequence whether or not it is correlated with a temporal sequence, but they are able to retrieve the temporal sequence accurately only when it is correlated with an associated spatial sequence (Shin and Ivry 2002a; for an indirect demonstration of the same point, see Shin and Ivry 2002b). A more recent study reached a somewhat less specific conclusion: “recall performance increases when both temporal and spatial organization correlate, but decreases when they clash” (Parmentier et al 2006).

What can we, as geographers, get out of this mass of specialized behavioral studies? The main message for geography teachers is that the brain appears to have a number of ways of organizing, storing, and processing information about spatial sequences. Moreover, different students may preferentially use different ways of interpreting a representation of a spatial sequence. This, in turn, may have different implications for their performance on particular kinds of tests of spatial memory.

As if that weren’t complicated enough, a completely separate body of research suggests that the nature of the environment can also have a strong influence on how easily the brain is able to organize environmental information into meaningful sequences. In short, some environments have “statistical structures” that lend themselves to being organized and remembered as simple spatial transitions, e.g. a gradual change from cold to warm temperature, or a fairly rapid change from low to high elevation. Other environments seem to lend themselves better to being interpreted as a set of discrete regions, with abrupt borders between them – like the fairly rapid transition between a factory and an area of housing for workers. After investigating several examples, one researcher concluded that the “experiments showed that the greater the statistical structure, the greater the reduction in RT [reaction time] with practice” (Stadler 1992, p 318).

That observation, reinforced by many other studies, leads to a modification of the take-home message: students should be encouraged to use the mental “tool” of spatial sequence or transition analysis in those environments that seem to have “statistically structured” place-to-place changes that can be interpreted as spatial sequences or transitions, rather than as more complex spatial patterns (Turk-Browne et al. 2008).

The ability to sense the “structure” of a space depends greatly on the direction that we travel through the space (I’ll cite one example here, from the reading I was doing for a science lesson on climate change, because the authors were good enough to put the term “spatial transition” in their title: Wood et al. 2011). Moreover, the number of turns that we make has a great influence on our ability to remember features along a travel route – a path with too many turns is less likely to trigger the sequential memory systems in our heads (Parmentier et al. 2005).



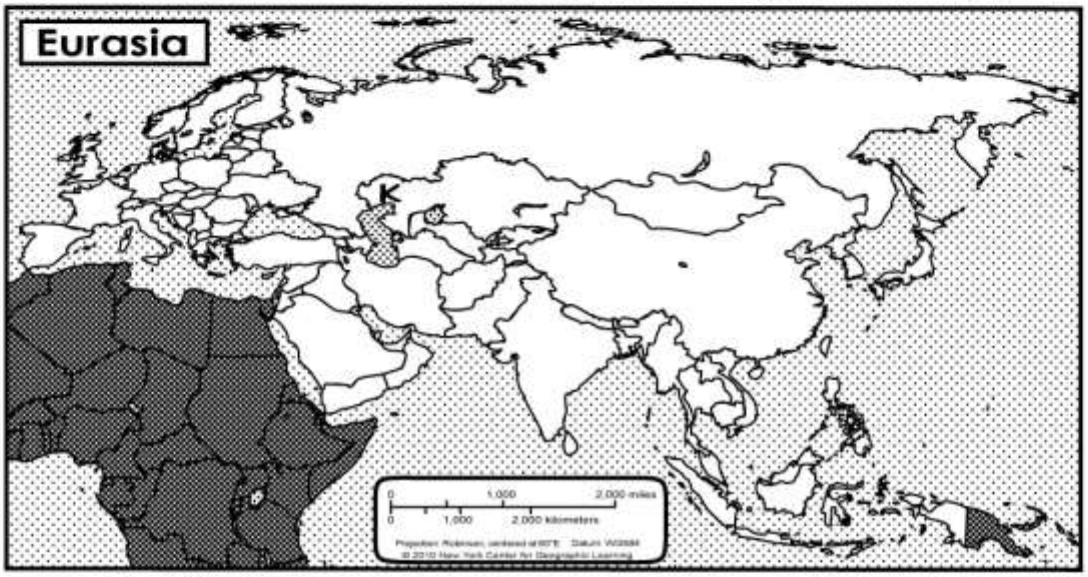
In short, it seems advisable to try to teach students how to figure out which mode of spatial thinking seems to fit a particular kind of environment (Lingwood et al. 2015). As the old carpenter’s adage says, if a particular part of the world looks like a nail, you should hit it with a hammer rather than a screwdriver or a saw! In short, if a part of the world has some observations or measurements that form an obvious spatial sequence with an easy-to-describe spatial transition from one place to another, we should encourage students to do that kind of thinking, rather than try to remember all of the facts about every place in between. That is the idea behind the sample student activities in this folder.

Getting Oil Out of Kazakhstan

In order to understand the geography of places, it is not enough just to know the conditions at the places. You also need to know about the connections with other places.

Background: The land around (and under) the northern part of the Caspian Sea in Kazakhstan (K) has three of the eight largest oil discoveries in the last 20 years. Unfortunately, those valuable resources are in a dry and sparsely populated area, far from the core areas of the world economy.

Options: The oil could go west in a pipeline toward Europe, north to Russia, east to China, or south to the Indian Ocean. Each option has advantages and disadvantages.



Your job: Gather information from maps and/or satellite images, For each route on list 1, pick the best description of its physical conditions from list 2 and its cultural conditions from list 3. Write those numbers on the E__ and P__ lines.

1. ROUTE	2. ENVIRONMENTAL CONDITIONS	3. POLITICAL CONDITIONS
Westward E__ P__	E1 - generally low land that gradually gets colder and covered by forest	P1 - many countries that were divided during the Cold War and must negotiate a pipeline right-of-way
Northward E__ P__	E2 - rugged mountains, with grassland and desert between the ranges	P2 - a single large country that was the core of the Soviet Union, which ruled over Kazakhstan for many years
Eastward E__ P__	E3 - mostly plains used to grow crops, and low hills covered by forest	P3 - small, ethnically divided countries that are involved in post-911 wars and terrorist activity
Southward E__ P__	E4 - grassland, very high mountains, a large desert, then forest and cropland	P4 - a single large country that has had trade links with countries around the Mediterranean for 2000 years

Then: Design a presentation to persuade people to consider the route you think would be best.

Sample dialogs, from two teachers trying to teach about the conflict in Darfur, Africa.

T: Today we are going to look at the environmental context of the Darfur situation. Look at your mini-atlas, and write a one-sentence summary of the general environment pattern of north Africa.

[After pair-and-share] S: there's rainforest near the equator, a big desert across the northern part, and like parallel strips of savanna and grassland in between

T: excellent! What are the main sources of human food in the rainforest? S: fruits from trees and animals that live in trees [or, slash-and-burn farming; either answer is OK for now]

T: and what kind of food do they raise in the savanna area? S: it looks like grain farming

T: how about the grassland close to the desert? S: they raise cattle and camels

T: good. Now, Darfur is right on the border between the grain-farming area and cattle-raising area; that's one important reason why they have a conflict over the use of the land in that part of Africa.

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T: Today's topic is the environmental context of the Darfur situation; look at your map, and write a one-sentence summary of what happens to the rainy season as you go north from the equator.

[After pair-and-share] S: the rainy season gets shorter as you go north

T: Let's explore some consequences of that gradual transition from rainy to dry. Tree crops, like bananas and date palms, need at least 8 months of rain. Where could people grow them for food? S: close to the equator?

T: right. Cattle can survive with only 3 months of rain, but they get bad diseases in places with more than 6 months. Point to some possible cattle regions, and check with your partners S: [murmur]

T: Now, suppose global warming makes the rainy season about two weeks shorter everywhere. Grain farmers need four months. Now look at Darfur. Its rainy season just got too short for grain, and cattle-raising people are moving in.

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These dialogs illustrate two different ways of reading a map of north African environments – as a set of discrete regions, or as a gradual transition from rainy all year to dry all year. Each set of questions tends to reinforce the original perception. The first dialog refines a regional image of Africa; the second one sets up an inquiry scenario about spatial sequences instead of a simple map-description task. It also treats land use as a cause-and-effect problem, not just a verbal association of plants with named regions.

Ideally, however, a teacher would shift back and forth between these worldviews, helping students translate a map of regions into a perception of gradual transition and vice versa. This would ensure that fewer students get left out, especially those whose natural inclination is to favor a specific mode of spatial thinking – either regionalization and spatial association, or sequencing and spatial transitions.

Additional student activities that involve thinking about spatial transitions

A. Making a “journey scroll” of a field trip or other walking or driving journey

1. Make a long scroll by taping several pieces of paper together and rolling them up like a roll of paper towels (or just use part of a roll of paper towels, or some other roll paper!)
2. Have students stop near the beginning of the walk and record what they see at one end of the scroll; that record can be a sentence, sketch, measurement, quote, even a poem
3. Go on to the next place, stop, and record something about it in the next part of the scroll.
4. Back in the classroom, use the scroll as a visual aid in describing what you saw on the trip.

Variation: collect leaves, stones, menus, business cards, or other objects and tape them to the journey scroll as illustrative artifacts in the appropriate place along the journey. (CAUTION: We work in New York: this is <u>not</u> recommended in places where streets are really dirty!)

B. Making a graph of building conditions along a street

This activity can be done from a car, bus, elevated rail line, or on foot.

1. Carefully observe building condition on a block (or take a digital picture for reference).
   - Note the material (brick, stone, stucco, wood, glass, etc.); the condition of the paint (fresh, dirty, faded, chipped, etc.); the conditions of the signs (if any) or other details; the condition of trees, bushes, or grass (trimmed, weedy, dead, missing)
2. Assign that block a preliminary score of 7 if you think it looks good, 5 if average, 3 if poor, compared to other blocks you may have seen in the neighborhood.
3. Put a dot to represent that block in the first column of the graph form (CD for a sample data form; or have students discuss and then design the data form as part of the activity)
4. Go to the next block (or several blocks, if you are doing a long transect with a car or bus)
5. Decide whether the building condition on that block is better, the same, or worse than the first one. Assign a reasonable number and record in the second column.
6. Continue for 5-20 sample points – observe, compare, assign numbers, and record
7. Connect the dots with a line to make a graph of changes in building condition (see CD)
8. If desired, compare with graphs of other variables that may be related, such as household income, elevation, slope, date of construction, family size – some can be observed, others must come from census records or other sources (see Urban Transition CD unit)

Variation: make graphs of other variables, such as building height (number of floors), yard size (as if you were making an estimate of mowing time), languages on signs, etc.

C. Making a graph of rainfall or elevation across a continent

This activity requires a thematic atlas, a good textbook, or a GIS data set.

1. Draw a line from the coast going into a specific continent in a chosen direction.
2. At reasonable intervals along that line (say 100 miles), note how much rain the map says falls in that place, and record the information in the appropriate place on a graph that has distance on the X-axis and data on the Y-axis (the CD has some sample graph forms).
3. Connect the dots with a line to make a graph of elevation, rainfall, etc.
4. If desired, compare with graphs of other variables that may be related, such as population density, land value, percent forest, crop yield, etc. The goal is for students to get in the habit of noting geographic transitions on any thematic map they may encounter.

Variation: Pre-make various profile graphs and have students match them with lines on the map – the CD has an elevation example for New York, related to the Erie Canal.

D. Making a graph of some variable along the course of a river, railroad, or road

1. At reasonable intervals along a route, record information from the map on a graph form.
2. Connect the dots with a line to make a graph of the information you recorded.
3. If desired, compare with graphs of other variables that may be related.

Variation: Pre-make profile graphs, and have students match them with rivers, trails, or other lines on the map – the CD has an example using major rivers.

In-Depth Review of Research About Spatial Sequences and Transitions

Before trying to review the empirical research that deals with thinking about spatial sequences and transitions, it may be helpful to step back and look at the mental actions that are required in order to describe the change in conditions between places.

1. A logical starting point is to notice that conditions are indeed different in two places. This is basically a form of comparison (as described in Essay 5). Comparison requires the use of some kind of working memory to store one observation or retrieved memory while we obtain another one. Then, we transfer both to the intraparietal sulcus area above and behind the left ear (for numerical comparisons, in most people) or the right ear (for luminance or complex size comparisons). That is the area where brains apparently make comparisons (Piazza et al. 2006. For different perspectives on process of comparison, see also Wolbers et al. 2004; Rivera et al. 2005; Dehaene et al. 2003; Kadosh et al. 2008; Troiani et al. 2009).

2. The simplest kind of analysis of a spatial transition (as opposed to a mere difference) occurs when we add a third observation from some place between the endpoints – in effect, we are comparing conditions in the middle with conditions at either end. This process must be learned, because sequences of three or more places "are more complex because they depict linear order" instead of mere association or containment (Casasola et al. 2003, p679; see also Yamamoto and Shelton 2009; for an exploration of the developmental process in young children, see O'Connell and Gerard 1994).

3. A spatial transition can be described more accurately if we gather information from additional points along the way. Unfortunately, this process seems to encounter some rather severe working-memory limits. This has been suspected for decades (e.g., Miller 1956) but is evidently still not a fully resolved issue (see, for example, Smyth and Scholey 1996; Fraser et al. 2004; Oberauer and Kliegl 2006; Hurlstone and Hitch 2015).

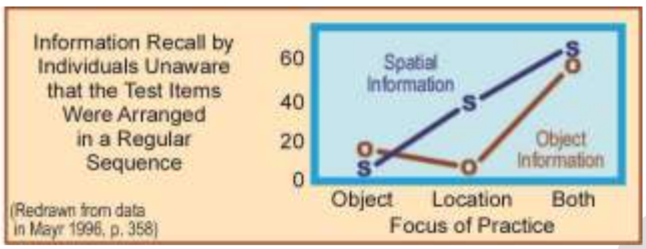
4. One solution is to store information about the sequential nature of the observations in a separate memory area. In effect, the brain appears to transfer some of the relevant spatial information from the general-purpose working memory to a part of the frontal lobe, roughly located inside your forehead above your left eyebrow (Romine and Reynolds 2004; Histed and Miller 2006; but there is also some evidence that, at least in some people, sequence information is stored as a set of associations, perhaps paired with some kind of marker – see Allen and Ondracek 1995; Ergorul and Eichenbaum 2006; Caplan et al. 2009; for an example of a large body of research on the role of sequence information in particular kinds of body motions, see Robertson et al. 2001; for proof that distinctions between even more different kinds of reasoning can seem blurred, see Gaschler et al. 2012).

5. These sequential observations or retrieved memories can then be brought back into the comparison area one at a time, in order to assess the nature of the change between each pair. This is the step where the two groups of "visualizers" appear to diverge (as described earlier). One group seems to take a mental snapshot of the sequence, presumably using parts of the visual processing system on the back right-hand side of the head, while other people seem to store a kind of primitive mathematical description of the trend, probably using the sequencer in the front and various areas around the ear on the left side of the head (Kozhevnikov et al. 2002; Vanucci et al. 2006; Li et al. 2011; for more recent studies that tried to pin down the internal brain structures that are used to process sequential memories, see Gevers et al. 2003; Schendan et al. 2003; Suzuki et al. 2005; or Ross et al. 2009).

6. Finally, when a series of observations have a kind of "statistical regularity," such as a steady increase or decrease over distance, the notion of a spatial transition seems to "have simple, data-reducing memory features [and therefore may be] the most economical to operate in memory

resource terms" (McGonigle and Chalmers 2001, p. 251). These authors quote an earlier book (Harnad 1987) as saying: "emergence of linear seriation behaviors . . . indicates strongly that there are core cognitive precursors of human abstract thought that derive from [sequential] acts of discovery." In short (as we have also said about other modes of spatial thinking), the human brain has a number of "shortcut" processes that reduce total effort, as well as demands on working memory. Thinking about spatial transitions is one powerful way to organize knowledge about aspects of the world that appear to have easy-to-describe patterns of change between two places.

The logical breakdown of these steps into a series of sub-processes, of course, can mask the fact that the analysis of spatial transitions seems to be a partially "hardwired" set of brain structures and processes. As such, they avoid much of the complexity by performing the task of thinking about spatial transitions more-or-less automatically, often without conscious thought (Turk-Browne et al. 2008). The result (for at least some people) is a seemingly intuitive understanding and relatively simple mental representation of the nature of change between two places. Indeed, at least some people seem to process information about spatial sequences even when they are unaware that features are arranged in a regular sequence (Mayr 1996).



With training, a person can learn how to gather sequential information more thoroughly. Those data can then be expressed in verbal or mathematical form. For example, someone might say "property values along Park Avenue decrease gradually until you get to Third Street, and then they level off" or "the land near the shore appears to rise in a series of small cliffs and relatively level plateaus."

Interpreting sentences like that, however, requires some prior knowledge of the meanings associated with semi-technical vocabulary such as level, cliff, or plateau. Partly to avoid the need for terms that might be ambiguous, people often use graphical or mathematical devices to express change between places (Tversky et al. 1991; Schiano and Tversky 1992; Tversky 2001).

Expressing a spatial transition in graphic form confers another huge analytical benefit. If the graphs of two spatial trends are reproduced with the same endpoints and distance scale, people can visually compare the graphs and assess the degree to which the two variables appears to be correlated (i.e., the major changes in one occur in the same places as the changes in the other). Partly because of its requirement that information be georeferenced to a common coordinate system prior to entry into the data storage area, a GIS can serve as a solid foundation for this kind of comparative analysis of spatial transitions (see the CD units on property values in Forest Hills or income in Washington DC).

It is possible to make a graph look even simpler by calculating ratios and other measures of relationship between two variables along a spatial transition. In the example cited above, one such ratio might be house value per thousand dollars of personal income – that requires us to remember just one number rather than two. Each additional step in this mathematical process, however, loses some of the information that was available in the initial observations. In short, there is an inevitable tradeoff between descriptive accuracy and communicative efficiency.

That tradeoff forms the basis for a separate and somewhat more pragmatic line of research, namely about the conditions that tend to promote or interfere with accurate memories of spatial sequences. This topic has been of innate theoretical interest since the 1970s (see, e.g., Lippman and Lippman

1976 or Howlett and Sitton 1977). As with many other topics in experimental psychology, there has been a resurgence of interest triggered by the development of brain-scanning technologies (e.g. Farrand 1996, Henson 1999, Histed and Miller 2006). What sets this topic of research apart, however, is its practical value in fields such as criminology, where an erroneous “eyewitness” account of spatial sequences can convict an innocent person or release a guilty one (Cornell et al. 1996).

All of these practical applications should serve only to reinforce the main message for teachers, namely that the organization of spatial knowledge into sequences is a distinct mode of spatial thinking. Some individuals do this kind of thinking better than others. Moreover, individual student performance on a spatial-sequencing task is not always well correlated with performance on tasks that involve other kinds of spatial reasoning, such as regionalizing, forming spatial hierarchies, recognizing spatial patterns, or assessing spatial associations.

Overlaps between thinking about spatial transitions and other modes of spatial thinking.

We have already noted a strong overlap between the processes of thinking about spatial comparisons and spatial transitions – a transition can be described as a sequence of comparisons with the aim of noting how things change as you go along a path. We have also noted that some analysts prefer to view spatial sequences as paired associations with some kind of mnemonic marker. There is also some evidence that people are “innately” able to do a kind of hierarchical reinterpretation of sequential observations. There are, however, good behavioral and neurological reasons to be precise in definitions and maintain a distinction between the kinds of spatial reasoning that also involve sequential logic and those that do not (Mammarella et al. 2006; Caplan et al. 2009).

Notions of spatial and temporal sequences seem to be especially important in learning to read (and reading is a profoundly sequential activity that often runs into working-memory constraints; to see how those constraints might be eased by hierarchical chunking; see Vinckier et al. 2007; for a semi-popular description of this process, see Dehaene 2009; for an earlier application of the same idea to interpret dyslexia, see Helland and Asbjornsen 2003).

Another fruitful logical interplay occurs between the ideas of region and transition. In effect, a region can be “interrogated” in terms of the nature of the spatial transitions between the core of the region and the dissimilar areas in all directions. For example, the transition between the boreal coniferous forest and the treeless tundra in northern Canada takes place gradually over the course of many hundreds of miles. By contrast, the transition between a similar mountain forest and the alpine tundra at higher elevation often appears in the form of a fairly sharp “treeline” that may be less than a hundred feet wide. Both transitions can be depicted as lines on page-sized maps of vegetation “regions,” but the differences in the transitions are likely to have implications for animal behavior.

This overlap between the ideas of region and transition has pedagogical implications. As noted in the sample dialog, some students may preferentially arrange their mental maps of many natural and cultural environments around the idea of regions, whereas others may find it more congenial to use the concept of transition as their organizing theme. Both groups should be encouraged to see that their preferred mode of organization is complementary to another perspective that others might find easier to use.

Only a few empirical studies in psychology have explored these connections (e.g. Helstrup and Magnussen 2001; Petzold and Haubensak 2004; Botvinick and Watanabe 2007). A few recent studies add complexity by suggesting that the mode of perception may influence the way the information is structured – an overview from a high vantage point might lead to a different mental image than a gradual encounter from a ground-level perspective (Tremblay et al. 2006). As a result, any conclusions that geographers may draw at this time should be listed as tentative.

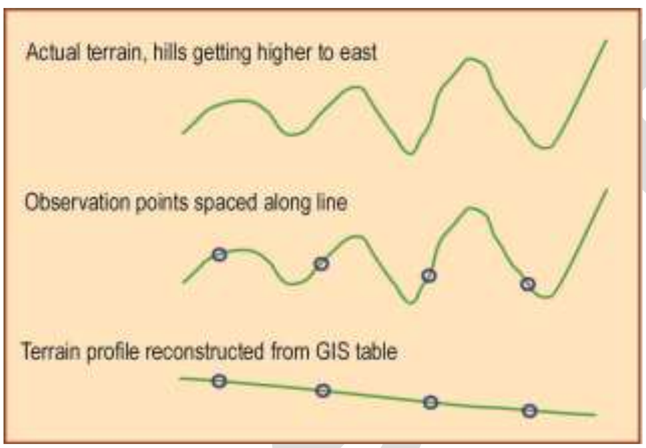
The same adjective – tentative – must be used with considerable emphasis in describing any ideas that people might infer from a handful of studies about male-female differences in spatial cognition, as exemplified by studies that seem to reveal a male advantage in the process of looking at contour maps and "seeing" slopes (gradients, or transitions in elevation; see, for example, Lanca 1998).

What is less debatable is that males in general tend to do better on tests that measure spatial sequencing, whereas females do better on tests that measure spatial associations. We will say more about this in the Detailed Review section of the Essay about spatial associations. For now, we will mention just a few studies that tried to compare the relevant processes directly (Ward et al. 1986; Sholl et al. 2000; Jones 2003; Vaquero et al. 2004; Chai and Jacobs 2009). 437

Issues with using a GIS to support thinking about spatial transitions

Some GIS software can produce graphs of data along a specified line. Basically, the GIS interrogates its data base to figure out the value at a number of sample points along the route. Therein lies the issue – the spacing of sample points can influence the perceived slope of the graph.

With elevation, this problem is most likely to occur in areas of intricate topography, such as a karst plain, glacial moraine, or dissected alluvial fan. Basically, the sample points may simply not be close enough together to "capture" the details of the terrain. In some cases, the sampled profile may actually misrepresent the actual topography.



One might think that the solution is simply to use sample points that are closer together. Fifteen years ago, the most commonly voiced objection to that strategy was storage cost – halving the distance between sample points (in each direction) would quadruple the number of data entries in a GIS table. As the price of computer memory and processing speed continues to fall, this objection is losing credibility. But there is a deeper problem – the original data set often had its own innate spacing between data points, which is often much greater than the resolution of the GIS. For example, weather balloons to observe conditions in the upper atmosphere are sent up every six hours at many airports around the country, but those airports may be spaced tens or even hundreds of miles apart. Census information is gathered from "tracts" and "minor civil divisions" that contain thousands of people and may extend for a dozen blocks in a city and a dozen miles in rural areas. Even a satellite-based map of land use or a digital elevation model of topography has an innate "grain size" – satellite pixels, for example, may be tens of meters in size, far too large to record small details such as cars or individual trees.

A GIS can easily make a graph of weather information from airport observations or personal income as reported by the Census Bureau. The resulting graph, however, cannot be reliably correlated with information gathered on a finer scale. For example, it is dangerous to take building condition, as observed on individual structures, and correlate it with household income obtained from census tracts. Add to that the fact that the building condition is observed today (e.g., in 2013, when this chapter was last edited), while the income information comes from the census for the year 2010.

This book is not the place to try to quantify the potential magnitude of error that may occur when people try to compare databases that have different scales of sample points. That investigation could easily take many years of work (I know, because I was involved in a fairly narrow error-tracing project in the 1980s, and one conclusion was that the results of a study about error in soil maps may be applicable only in the immediate area of the reliability test (Gersmehl and Brown, 1986; Brown and Gersmehl 1987a and 1987b). Indeed, it would probably require another book simply to review the research that has been done on that topic since we did our studies.

In this essay, therefore, we should simply conclude by noting three things:

1. thinking about spatial transitions is a powerful way to organize our knowledge of various aspects of the world,
2. a GIS can greatly aid that process by automating the production of graphs that summarize the changes that occur along specific lines across a map, and
3. it is important to know the actual resolution of the original data when interpreting a graph that is made at the output resolution of the GIS, because the GIS display may give an impression of much more precision than is warranted by the nature of the input data.

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