Thinking About Spatial Patterns

True randomness is rare; most things have patterns, and patterns are caused by something. (Drafted 2008, revised 2011, updated 2015)

This chapter is about organizing and representing geographic information by observing and describing the arrangements of features, conditions, or connections in an area. Authors of popular books or magazine articles sometimes describe the human brain as "a pattern-seeking machine." The kinds of patterns that they mention, however, are not always spatial - they may be temporal, mathematical, logical, even kinesthetic or musical. As a result, their idea of pattern often includes things like sequences (which we treat in Chapter 8), nested hierarchies (Chapter 9), associations (Chapter 12), and so forth. When you lump all of those things together, the definition of "pattern" becomes so broad that it embraces almost everything we might see on a map. That, in turn, makes the concept rather difficult to use in a classroom, because a child could answer "yes" to the question, "do you see a pattern on this map?" and be "seeing" almost anything!

This chapter will define "spatial pattern" narrowly, as an alignment, arc, cluster, ring, wave, bias, mirror image, or other spatial arrangement that is not random. That definition requires us to deal with the concept of spatial randomness, which can be difficult for students to grasp. To help clarify this concept, this chapter and the accompanying CD units will use examples from fields as diverse as geology (earthquakes), wildlife biology (tiger sightings), epidemiology (cancer clusters), criminology (murder statistics), urban design (settlement patterns), and public art (statue locations).

For convenience, we can start by grouping patterns into two broad categories, which we will call whole-map patterns and local patterns.

- 1. At the whole-map level, pattern analysis deals with major deviations away from a random arrangement, which by definition is patternless:
 - even patterns have objects that are spaced more evenly than one would expect if they were random
 - clustered patterns have more objects in bunches and groups than random patterns
 - balanced patterns have roughly the same number of objects on each side of any line drawn through the middle of the map
 - biased patterns have more objects on one side of the area, as if something tended to push them toward that side
 - centripetal patterns have more objects near the center of the area, as if something pulled them toward the middle
 - centrifugal patterns have more objects near the edges of the area, as if something pushed them away from the middle
- 2. At the local or micro level, pattern analysis depends more on the relationship between individual objects and their neighbors. Are objects aligned in a particular direction (and therefore their nearest neighbors are likely to be in that direction (or its 180-degree opposite)? Are objects arranged in an arc, or a circle, or some other shape that can be described? Do groups of objects form larger patterns, such as mirror symmetries or wavelike arrangements?

In sum, one major goal of teaching about pattern analysis is to agree on clear definitions of some conventional terms for spatial patterns. People can use these definitions to evaluate patterns they may encounter in news media and other aspects of daily life. When combined with shared map images (whether physical or mental), these pattern terms can then help someone communicate about patterns by comparing them (e.g., by saying something like "houses in this neighborhood are aligned, but not quite as noticeably as the Israeli settlements on the West Bank" – see the student Activity).



Research on Thinking about Spatial Patterns

Even with the major restriction of scope that we described in the introduction, we find that the concept of spatial pattern is still of interest to people in a surprisingly large number of academic disciplines, including agronomy, archaeology, architecture, botany, costume design, dance, ecology, economics, geology, graphic design, and history, to name just a few in alphabetical order. The diversity of research about pattern or shape poses a huge problem in trying to figure out what insights those inquiries can contribute to our understanding of the process of thinking about patterns on maps. In general, groups of researchers in different disciplines have tended to focus on different aspects of pattern-seeking, such as:

- estimating alignment of lines or objects,
- discerning the edges of objects,
- recognizing faces or other shapes,
- noting symmetries and identifying major axes,
- predicting the arrangement of objects if seen from a different perspective,
- accounting for the effects of illumination,
- choosing the best move in board games such as chess
- picking a specific "target" image out of a mass of distractors, and so forth
 - (Tarr et al. 1998; Lee et al. 1999; Patel and Salthian 2000; Awh and Pashler 2000; Hegarty and Waller 2004; Scherf et al. 2009; Li et al. 2011; Marchette and Shelton 2010; van den Berg et al. 2011; Wan et al. 2011; Becker et al. 2014).



If the research "picture" is so cluttered, why should we deal with all of these different topics in a single chapter? Why shouldn't we consider the possibility that "pattern recognition" might actually be a number of independent modes of spatial thinking?

One answer to that question comes from the handful of studies that have specifically tried to monitor people as they do several pattern-analysis tasks rather than just one. Some of those studies have used brain-scanning technology to gather information about what parts of the brain became active during these tasks. That research tends to conclude that various kinds of pattern recognition use the same general neural structures in the brain. According to the authors of one recent study, their investigations "provide clear evidence that a prefrontal– posterior cortical system implicated in mental rotation, including the occipitoparietal regions critical for this spatial task, is [also] recruited during visual object categorization" (Schendan and Stern 2007, p 1264; see also Kanwisher et al. 1997; Gilbert et al.1998; Aylward et al. 2005). In other words, the tasks of identifying the alignment of 3-D blocks and describing the shape of flat objects may seem different to a casual observer, but they appear to use the same brain structures and therefore must have some underlying unity. Other researchers, however, have suggested that people use different brain structures during pattern recognition and putting patterns into categories (see, e.g. Reber et al. 1998; Ellison et al. 2004).

That tentative conclusion is complicated by the same fact that has added complexity to our discussions of other modes of spatial thinking. That fact is the choice of frame of reference, which has many implications, including the "selection" of the particular parts of the brain that get involved in doing a

task (Hinton and Parsons 1988; Galati et al. 2000). Additional complexity is added by some evidence that people use a specialized kind of pattern analysis for face recognition, and that process appears to involve brain structures that are at least partially separate from general pattern-recognition areas (O'Craven and Kanwisher 2000; Simons et al. 2001; Andrews and Ewbank. 2004; Aylward et al. 2005; Kadosh and Johnson 2006; Michel et al. 2006; Yue et al. 2006; Zhao et al. 2014; for a contrary view, see Haxby et al. 2001). The possible presence of a parallel and partly independent face-identification structure, in turn, may help explain why different students are attracted to or put off by maps that use face diagrams to communicate multivariate information (Chernoff 1973, 1975; Turner and Tidmore 1980; Flury and Riedwyl 1981; Spinelli and Zhou 2004).

Face recognition is just one example of a frequently-observed kind of mental interaction between conscious thought and pre-conscious visual processing. That interaction, in turn, is one reason why pattern description remains part science and part art, something that people seem to learn by "bottom-up" inference from experience as well as "top-down" application of rules (Smith and Minda 2002; see also Gibson and Pick 2000; Downs and deSouza 2006; Harel et al. 2010; Kok and deLange 2014).

At some stage in their quest to become skilled map readers, therefore, students should see enough examples to become familiar with the conventional vocabularies that people have developed to describe patterns on maps – words like balanced, biased, aligned, arcuate, wavelike, symmetrical, etc. A teacher might initiate that process of vocabulary building by providing a well-illustrated first look at the idea described in the introduction, namely that map patterns can be crudely divided into two broad groups: macro patterns (whole map patterns) and micro patterns (partial or local arrangements). Some of the files on the CD are included specifically to help that discussion.

In both whole-map and local-pattern analysis, researchers often find that pattern language can influence perception (e.g., Notman et al. 2005). As with nearly every other mode of spatial thinking, but perhaps to an even greater degree, the available research seems to suggest that the process of discerning spatial patterns can be strongly influenced by prior knowledge and experience. For example, if observers are primed with prior experience in angle discrimination, their perceptions are measurably different from those of people without the prior experience. "This argues strongly that [angle] category learning can alter our perception of the world" (Notman et al. 2005). In another research lab, children viewing a disk at an oblique angle in a dark room tended to exaggerate its circularity – unless they were told in advance that it was actually an elliptical disk, and then they did not (Mitchell and Taylor 1999).



Other researchers have extended this idea to note that prior knowledge of the existence of a spatial pattern can alter the strategies that children use in solving spatial problems, such as finding an object buried in a sandbox (Cornell and Heth 1986; Uttal et al. 2001). In doing so, children begin to master the kind of spatial thinking that later can be used to address important issues in applied geography, such as the search for the causes of spatial clusters or other patterns of disease, crime, or pollution (for examples and reviews of some of these fields, see Gattrell et al. 1996; Lundrigan and Canter 2001; Wartenberg, 2002; Goovaertz and Jacquez 2004; for a general overview, see MacEachren and Ganter 1992; for a review of applications across a range of social sciences, see Logan 2012).

In short, the recognition of patterns on maps is often the first step in formulating hypotheses about the reasons why phenomena are not arranged randomly. These hypotheses, in turn, can help us uncover causal connections that otherwise might have been difficult to discern.



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Sample dialogs, from two teachers trying to teach about the location of forts

- T: This map shows the locations of colonial forts at the time of the Revolutionary War.... The map says many of the forts are arranged in a clear geographic pattern. Why would people want to build forts in a pattern like that?
- S: Because they were building them all along a road?
- T: That's one possibility. Can you think of another theory? S: [silence]
- T: Well, what if we looked at a map of physical features? Is there a pattern on this map? Do you see something that looks about the same as the pattern of forts?
- S: The forts seem to follow the blue line across the map
- T: That's good. The forts and the blue line have the same general pattern.

T: This map shows American forts during the Revolutionary War. They are obviously <u>not</u> scattered evenly across the map. How would you describe their pattern?

- S: some are like in a line
- T: Good. Does that line go east-west or north-south? S: a big line goes east-west
- T: What other features have an east-to-west line pattern in New York? S: [silence]
- T: What kind of map could help here? S: a road map like this?

T: Good suggestion! But what might influence where they put roads? Does something else have a clear east-west alignment? S: On this map, it looks like a river runs there.

- T: Great. Why would roads often go parallel to rivers? [accept any reasonable answer]
- T: And why would they build the forts there? S: to protect the roads?

These dialogs underscore a familiar refrain – the cues that help students apply a specific mode of spatial thinking can be quite subtle, and a teacher has to remain alert to equally subtle clues in student reaction – in short, "the devil is in the details," and the details are cumulative

The two dialogs are the same length (120 words). The second one, however, has set up a situation where students are more likely to link the pattern-analysis areas of their brains with the verbal and mathematical areas. Twice in the dialog, the first teacher asked a simple yes-no question ("Can you see a pattern?" "Is there a pattern?"). The problem with that kind of question is that students often treat it as rhetorical and answer yes, of course. But when that happens, the teacher does not really know if different students actually are seeing the same thing on the map, and the followup questions do little to clarify that point.

The second teacher forced a choice between multiple and equally plausible options, by using questions that can be answered only by looking at the map. In doing so, that teacher also introduced (or reviewed) a notably larger amount of pattern language (specific words like scattered, grouped, aligned, parallel). Making an explicit verbal or mathematical description of a geographic pattern makes it much easier to remember than if it remains just a visual image, with or without a name.

Additional student activities that involve thinking about spatial patterns

A. Make a sketch map of interesting lists – states whose senators supported a particular bill, sites recommended for a new factory, locations of bird-flu cases, states with low unemployment rates, etc. Making sketch maps is important both as a way to teach about spatial patterns and as a "body-language" message that knowing the locations of some things can help us understand them.

My current example is my breakfast-reading this week, a National Research Council's report about Internet-based professional development for in-service teachers (NRC 2007). It's an interesting and insightful report, but . . . the committee co-chairs are from Iowa and Massachusetts; the other members come from Massachusetts (2), Maine, California (2), Nevada, and Washington DC. Put those locations on a map, either physically or mentally, and you realize that they are tightly clustered and centrifugally biased – the committee has no one from the Rust Belt, Great Lake States, Dixie, the Great Plains, or the Pacific Northwest, and no one from a major urban school system (the ones with the greatest teacher turnover and therefore arguably the greatest need for professional development). The question, of course, is whether a biased pattern of authorship results in a biased report!

B. Describe the pattern of trees in different parts of a local park (IF that park is suitable for this purpose). Some parks have

- "natural areas" with essentially random tree patterns,
- "picnic areas" with mowed grass and scattered but somewhat even spacing of large trees,
- "formal-garden" areas with trees in rows or arcs, and/or
- treeless "playground areas" with trees around them in a centripetal pattern.

Practical application? here's one: what kind of pattern makes trees more vulnerable to wind or lightning damage? Or, what kind of pattern makes tree diseases hardest to control?

C. Use an internet yellow pages or mapping program to make maps of some specific kinds of retail or recreational activities, and then describe their patterns. For example,

- Law offices are often clustered near the courthouse.
- Antique stores and car dealers are often clustered with others of the same kind.
- Schools, libraries, and clinics tend to be spread evenly through the population they try to serve.
- Drug stores and grocery stores are likewise spread evenly, with one caveat if two major chains are competing for a local market, they often occur in pairs, like Walgreen and CVS right across the street from each other in several Fort Wayne neighborhoods. Is that pattern the most efficient for minimizing travel time for consumers? Of course not, but . . .

Practical application? planners usually make maps like this in deciding where to locate new facilities. Indeed, a major use of GIS in business or public policy is to provide data about areas that appear as "gaps in the coverage" of some service or retail activity (this actually involves thinking about spatial auras (Chapter 6) and associations (Chapter 12), but thinking about spatial patterns is what helped choose the areas to investigate).

D. Don't just look at textbook or news maps or photos (or Google-Earth satellite images). Explicitly describe the spatial patterns of specific features that appear in them – mountain peaks, blue tarps over roof-damaged houses in post-Katrina New Orleans, earthquake epicenters, wind generators, endangered coral reefs, tiger sightings, rock music concerts, burglaries, traffic accidents, foreclosed houses, UFO sightings, the list of potential topics is almost endless. CAUTION: some kinds of data are much easier to obtain than others, and rightly so – this is a free country, and people have a right to privacy in some parts of their lives. Even so, there are plenty of spatial patterns out there for easy observation by anyone who is aware that a spatial pattern can reveal information about causes that might be hard to discover by any other means.

Note: This page did not have any lists of detailed steps to follow, because most applications of this mode of spatial thinking have only three steps: look at a map or satellite image, describe the spatial pattern you see, and make a hypothesis about why those features occur in that pattern.

Detailed review of research on thinking about spatial patterns

A detailed review of research on this topic is complicated right from the beginning by two facts. The first complication is the general observation that the concepts of shape, arrangement, and pattern have meanings that seem to overlap in different ways for people in different disciplines. The second complication is the specific observation that the phrase "pattern separation" has a very narrow and somewhat unique meaning among vision scientists. This is important because vision scientists are a key part of the research effort. They have that role because the analysis of spatial patterns begins in the visual cortex in the back of the brain. Here, in a nutshell, is the logic they use:

- 1. People do not have enough memory capacity to remember all the details of a scene,
- 2. For this reason, human memories tend to simplify objects greatly, often reducing them (usually unconsciously) to simple geometric solids such as spheres, cylinders, and boxes.
- 3. This simplification then comes back to haunt anyone who is trying to decide whether a viewed scene is a new one or a just different perspective on a familiar scene.
- 4. "Pattern separation" is the term that has been coined to describe the process of making that judgment, although as of 2008 "how the brain accomplishes this has remained elusive" (Colgin et al. 2008, p 469; see also Leutgeb et al. 2007; Bakker et al. 2009).

When a geographer talks about spatial patterns, however, the concept does not imply an attempt to represent all the features of a scene. In fact, a geographic pattern is usually something that we <u>extract</u> when we make a thematic map or other geographic representation, e.g. a map that shows the spatial arrangement of just one category of things, such as earthquakes, oak trees, UFO sightings, law offices, tornado touchdowns, or Baptist churches. A geographer's working hypothesis goes like this: if a particular kind of feature has a non-random spatial arrangement, that pattern probably reflects the influence of some causal factor that is worth identifying and exploring. For that reason, the overall shape and other characteristics of the pattern can provide clues about the nature of that force.

For example, at a global scale, the aligned patterns of earthquake epicenters helped buttress the theory of plate tectonics, with its novel idea that the earth surface consisted of independent pieces of solid crust that caused earthquakes near their edges when they collided with or slid past other plates (NRC 2006). At a much finer scale, the clustered patterns observed in populations of shellfish can give us useful insights about feeding behavior and response to predation (Kostylev and Erlandsson 2001 and Van de Koppel 2008).

In using this narrow definition of pattern, we still have to note that the recognition of spatial patterns relies partly on the same perceptual systems that are used to gain information about the locations and identities of multiple objects in space (Faillenot et al. 1999; Winn et al. 2005; for an articulate acknowledgement that the human eye-brain pattern-recognition system performs far better than any robotic system that has been developed to date, see Serre et al. 2007).

Our task in this essay, therefore, is to look at the vast body of general shape-recognition research and try to pull out those conclusions that appear to be relevant for a study of geographic patterns on maps. Here are a dozen relevant research findings, grouped into four categories:

Category 1: Research about object recognition and pattern separation

1. The human brain has an impressive ability to reduce a perceived image to a few simple shapes, by applying a few simple but powerful rules. This reduction is necessary because the alternative is impossible: there is no way we could remember all of the different ways in which we are likely to see the same familiar object. Consider, for example, a house pet. The blunt fact is that Muffy the cat is capable of assuming many poses, and we are able to view those poses from many angles. If we tried to remember each one individually, as something like a snapshot, we would quickly exhaust even the immense storage capacity of our brains. As a result, humans have developed sophisticated ways of reducing Muffy to a few simple shapes (cylinders, spheres, cones), a few simple rules for connecting them, and a simple impression of surface covering. Then, to simplify things even further, we actually seem to remember only a few of those pose models, and we call upon our mental rotation ability to construct the in-between poses as needed (Tarr and Pinker 1989). A decade later, researchers showed that different parts of the brain seemed to take a leading role when we try to identify familiar figures in contorted as opposed to "normal" poses (Laeng et al. 1999).



Another decade of research tried to examine specific parts of the scene, such as the priority of focus on specific pattern "wavelengths" in an image (e.g. Grent-'t-Jong et al. 2006; Goffaux 2008; Goffaux et al. 2011; Koivisto et al. 2014). It seems plausible that these skills of pattern simplification, storage, and recall are what we apply to the task of interpreting something like a dot map of population or a choropleth map of family income (for a wide-ranging review that suggests a variety of hypotheses worth investigating, see Pinna 2011).

- 2. Unfortunately, the research also shows that different people often construct different mental models of the same cat as it moves around. As a result, there is "no evidence for universally valid canonical views: the best view according to one subject's data was often hardly recognized by other subjects" (Cutzu and Edelmann 1994 p 3037). Photos and other representations in geography classes, therefore, should include multiple views of important features, especially if the purpose of the photo is to trigger some kind of prior-knowledge recognition from a range of students with different backgrounds.
- 3. Fortunately, individual elements on a map do not move relative to each other, unlike a cat walking through a room, or even a static scene that the viewer can move through (Auvray et al. 2007). This "advantage" of still maps may, in a backhanded way, help explain why research by cartographers seems to say that many people have a hard time extracting information about specific places from animated maps (Griffin et al. 2006; but see also Harrower 2004).
- 4. The working memory that is used to store impressions of pattern and shapes is finite and perhaps fixed (Awh et al. 2007), but there appear to be individual differences in both its size and speed (Bleckley et al. 2003). Moreover, recognition of a pattern often permits more efficient storage of details (a song that we have been singing about every mode of spatial thinking so far! see Wheeler and Treisman 2002, p. 55: "one possibility is that participants stored the occupied locations as a simple overall shape or configuration rather than remembering each square's location individually")



5. Young children appear to be able to recognize various kinds of spatial patterns at a much younger age than they are able to communicate about them, even with simplified tools such as sticks rather than pencil and paper (Tada and Stiles 1996; Bouaziz and Magnan 2007; Ferber et al. 2007; compare the role of puzzle play as described in Levine et al. 2012).



This insight into the development of pattern skills has two implications for geographic education. The first implication is that explicit discussion of spatial patterns should begin at an earlier age than most American curricula suggest. The second implication is that primary-school lessons should include a range of ways to depict spatial patterns, including things like foldout mountains placed on a floor map, coins stacked to represent cities, wooden blocks to show arrangements of houses, and so forth. Our "K-4 on the floor" sessions at libraries and in schools have featured a wide range of manipulables that reduce the need for trying to represent objects with drawing skills that may not be up to the task yet (see the folder called Representing Our World on the CD in Teaching Geography (Guilford Press, 3rd edition).

Category 2: Research about scale and pattern recognition

- 6. The size at which we first see a shape has an influence on its memorability. In fact, changing its size greatly can result in the brain conceiving of it as a different object (Jolicoeur 1987). It follows that a spatial pattern that is readily apparent on a map at one scale may be difficult to see on a map with a different scale. Classrooms and textbooks should therefore feature more maps with different scales (and scale-adjusting software programs like Google Earth can be used for more than simply finding the location of the school and student's house!)
- 7. Even on the same map, people seem to differ in their ability to recognize whole-map as opposed to local patterns. Early studies suggested that most people employ a coarse-to-fine strategy, looking for broad patterns first and then zooming in on details (Schyns and Oliva 1994). Developmental psychologists in the same decade, however, reported that many children tended to favor looking for local patterns first, even though they could be persuaded to look for larger patterns (Akshoomoff and Stiles 1995; Burack et al 2000; for an update, see Scherf et al. 2009). At the same time, magnetic imaging studies concluded that the brain processed local and global information on opposite sides of the head (Martinez et al. 1997; Shipp 2011). That fact, which seems to be well supported by many other studies, has many implications for processing speed of different kinds of patterns, as well as linkages with working memory and connections with other geographically-relevant brain processes such as sequencing or size comparison.

Meanwhile, eye-movement studies noted that people shifted their focus from large patterns to small details fairly soon, even when mathematical models predicted that it would be more efficient to continue looking at larger patterns (Araujo et al. 2001; compare the discussion of saliency and eye movements in Bruce and Tsotsos 2009; for an earlier cartographic study using the same technology, see Dobson 1977).

8. The age-related shift in focus from local to global may be due to a "hard-wired" tendency to build mental models in a kind of "fragment-based hierarchy," with the lowest level of the hierarchy consisting of "simple 'atomic' fragments, which typically contain edges, corners, or lines" (Ullman 2007). This line of research provides a kind of neuroscientific foundation for earlier speculations about "Gestalt principles" such as alignment, proximity, and continuity (for reviews and sample experiments, see Zucker et al. 1983; Pani et al. 1996; Regan et al. 1996; Williams and Thornber 2000; Feldman 2001; Elder and Goldberg 2002; Boduruglu and Shah 2004; Scheessele and Pizlo 2007; Vinburg and Grill-Spector 2008). As noted in Chapter 9, about spatial hierarchies, these findings about scale and perception can have significant implications for map design in textbooks and classroom presentations. Consider, for example, the scale issues raised by various patterns (macro biases, meso spacings, micro alignments, etc.) on a simple map of settlements in one state:



Category 3: Research about object boundaries and pattern symmetries

- 9. The issue of object boundaries and partition is especially important in recognizing shapes. As one psychologist is fond of saying, "The world is not a coloring book" - it does not have lines drawn around objects to aid us in telling them apart (Pinker 1997, p. 6). Research suggests that the search for abrupt color changes, shape concavities, and other hints that might mark the edges of objects is something that happens very early in visual processing, and may even be [mostly] unconscious (Hulleman et al. 2000; Yee et al. 2010). At that point, the brain appears to shift from inductive, parallel perception of the entire visual field to an attention-driven, serial form of examination of specific areas. The shift from early parallel perception to serial attention seems to happen quite soon (Rousselet et al. 2004; but it may continue through adolescence, according to Scherf et al. 2009). In fact, it might be at least partly under volitional control (Sowden and Schyns 2006; Slagter et al. 2007). Moreover, the connectedness of the outer boundary of a perceived object appears to be more important than the coherence of inner boundaries (Saiki and Hummel 1998; Garrigan 2012). All of these findings have implications for map design, especially the selection of line-generalization algorithms for basemap borders – a simple mathematical smoothing (easily done in a GIS or vector drawing program) may be much less desirable than a selective emphasis on particular coastline features that have significance as anchor points for other spatial patterns or associations.
- 10. The brain appears to have powerful "tools" for recognizing symmetries and repetitive patterns. Of those, symmetries are usually easier to recognize than repetitions (Corballis and Roldan 1974; Nucci and Wagemans 2007), and the search for concentric patterns seems to use a faster but less precise brain network than the search for parallel patterns (Aspell et al. 2006).



In any case, one is more likely to find symmetries <u>within</u> rather than <u>between</u> prior-recognized objects, whereas repetitive patterns are easier to see <u>between</u> objects rather than <u>within</u> them (Bayliss and Driver 1995). Children appear to recognize many kinds of symmetries at quite early ages (Bornstein and Stiles-Davis 1984). Orientation and distance (the scale effect of point 6 again!) have a strong influence on the ability to recognize symmetries in dot patterns (Wenderoth 1995; Karnath et al. 2000. For a review that tries to tie these ideas back to early Gestalt concepts, see Nucci and Wagemans 2007; for a hypothesis about a "weight-of-evidence" decision process in the brain, see Csatho et al. 2003; for a description of a neural mechanism that appears to be crucial in recognizing repetitive patterns at different scales, see Hadjipapas et al. 2007).

Category 4: Research about conscious attention and the role of language in pattern recognition

- 11. The recognition of spatial patterns is inextricably linked with the question of visual attention and the ways in which viewers can direct their attention to different parts of a scene (or map). Suffice it here to say that the patterns you see depend in part on where you look, but where you look often depends on your expectations, as well as hints of the patterns you might see "out of the corner of your eye" (for glimpses into that vast topic, see Corbetta et al. 1990; Epstein et al. 2003; Ishikane 2003; McMains and Somers 2004; Deco and Heinke 2007; Finkbeiner and Palermo 2008; Yamamoto and Philbeck 20113; for a sophisticated cartographer's take on how those ideas might influence map design, see Lloyd 2005).
- 12. Finally (on this already long but still incomplete list), we should cite some examples of research that reinforce the idea that language and prior experience can "prime" people or help them build "perceptual sets" that predispose them to recognize specific kinds of patterns in particular situations (for a summary of a "bottom up" priming perspective, see Michelon and Koenig 2002; for summaries of the "top-down" perceptual approach, see Balcetis and Dale 2007; Wolfe et al. 2011; Davidesco et al. 2013; for evidence that either one can lead to learning-related physical changes in brain structure, see Aizenstein et al. 2000; for discussions about the role of conscious attention, see Hopfinger et al. 2001; Schenkluhn et al. 2008; Hsu et al. 2011; Lipinski et al. 2012; for samples of the relatively small number of cartographic studies that tried to address these issues, see Slocum and Gilmartin 1979; Maier 1999).

And then . . .

13. As a kind of postscript, we mention a fascinating study that takes advantage of the fact that the Japanese language has several different systems of writing. The research found that reading either script engages a number of shared brain areas, but learning to read the complex Kanji system of characters appears to make more use of a "downstream" part of the brain on the side of the head, whereas learning to read the simplified Kana syllable symbols seems to make more use of "upstream" areas in the back of the head (Thuy et al. 2004; Nakamura et al. 2005). By inference, it is plausible to hypothesize that simple and complex map symbols are likely to be

decoded in different parts of the brain, with different connections to working and long-term memory (as well as the parietal, temporal, and frontal brain areas that are involved in spatial comparisons, spatial hierarchies, and spatial sequences, respectively).

- 14. As a second postscript, let us add that there is some intriguing research to suggest that a person's emotional state and sense of control can have an effect on the likelihood of recognizing actual and illusory patterns (in other words, the willingness to accept that a given arrangement on a map is a significant pattern or simply random see Whitson and Galinsky 2008). This adds yet one more dimension to an idea that cartographers have held for a long time, namely that map perception is an active process, not a passive "reception" of a message that is "sent."
- 15. And finally, as a third postscript, let us add that there is another equally large body of research that deals with computer pattern recognition. We have cited very little of it in this chapter, for reasons that were explained in Chapter 6. For one thing, it is simply harder to find, and much of the best research is kept from public access by commercial or military barriers. One form of indirect evidence for this statement is the fact that electronic searches for books about the subject tended to elicit lists of books that are relatively old, quite expensive, but still in print (one of our searches noted Kittler et al. 1982 at the top of the list, even though it was 26 years old at the time, cost \$399 when new, was still in stock in late 2008, and had no used copies available). Other articles appear just as tantalizing abstracts of conference presentations or posters (e.g. Rinkus 2005). If you are interested in more information about computer pattern recognition, we encourage you to conduct your own searches we would greatly appreciate a concise summary of the results!

In the meantime, our impression is that this chapter is already long enough to make the main points:

- spatial pattern recognition is a complex, multifaceted process,
- it involves a number of brain structures, some of them operating pre- or sub-consciously,
- it consists of a shifting mix of perception-driven ("bottom-up") and intention-guided ("topdown") processes,
- there are significant individual differences in children's ability to see and describe patterns (and a person's verbal descriptions are not always valid indicators of what the person sees!),
- adult intervention, particularly by providing language to assist the process, can help children greatly improve their performance,
- skill in spatial pattern analysis may have positive spinoffs in other school subjects such as mathematics, science, and perhaps even language arts,



 - and finally, better understanding of things that facilitate or impede pattern recognition may have implications for many aspects of education (see, for example, the role of interference in letter recognition, as described in Fernandes and Guild 2009 or the discussion of visual crowding in Whitney and Levi 2011).

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

As we noted earlier, some early articles by cartographers lumped a lot of what we discuss in this whole series of essays into a single category called something like "pattern identification" (e.g., MacEachren and Ganter 1992). There is a neurologic justification for this, based on the fact that all forms of map reading by sighted people must, by necessity, begin with a visual examination of the map. For that reason, the first parts of the brain that get to look at the map are the frontal eye-field areas and the primary visual cortex in the back of the head. We think, however, that it is worthwhile to make a distinction between "simple" pattern analysis, which takes places early in the visual stream and then "sends the results to" the verbal areas of the brain, and other forms of spatial thinking that also involve places like the intraparietal cortex (for spatial comparisons), temporal lobes (for pattern association), or pre-frontal structures (for spatial sequencing).

The confusion arises because "simple" pattern analysis is neither simple (as evidenced by the 15-item list above) nor isolated – in fact, a message about a spatial pattern often becomes the raw material for other modes of spatial thinking, such as comparison, sequence analysis, analogy, regionalization, and, especially, association with other geographic features and patterns.

So be it. To paraphrase a quote reproduced elsewhere in this book, if the human brain were simple, we'd have built a computer that works better than the brain does for complex tasks like pattern analysis, not just faster for simple tasks like measuring distances and computing averages.

That blurring of distinctions is especially noteworthy when we look at the possible overlap between the concepts of spatial pattern and spatial sequence. The confusion arises because many spatial sequences can have patterns in them – regular repetitions at predictable intervals, like waves on the ocean or alternating houses and garages along a street. The distinction, as with many other possible overlaps between modes of spatial thinking, can often be resolved by asking a question about priority: Did you notice the regularity of a wavelike pattern first, and then try to describe the direction and spacing of the waves? That would be a form of pattern analysis. Or did you make a series of observations, try to describe the trend, and then notice a regular, wavelike alternation of high and low values? That would constitute a careful analysis of a spatial arrangement on a map. That is precisely what we mean by individual differences in the deployment of various modes of spatial thinking to interpret a map. And it is why a careful teacher must be alert to the nuances of children's attempts to describe what they see on a map.

6

Issues with using a GIS to support thinking about spatial patterns

This is another section that can be relatively short in this essay, IF you also read the same sections in the other essay, because the major issue is the same story about the spatial precision of input data. The blunt fact is that the spatial patterns of many things can look very different, depending on whether

- A features are displayed in their precise locations, or
- B their locations are partially masked by being incorporated into averages or other mathematical ratios that are calculated for larger areas, such as census tracts, police precincts, states, or countries.

For example, a spatially repetitive pattern of soil types is the rule in most landscapes, as hill after hill is topped by well-drained soils that are significantly different from the poorly drained soils that form in the valleys between the hills. At a county scale, however, the best that we can often do is to map the area as a too-intricate-to-separate geographic association of two different soils, with different crop yields and engineering implications. For more about this, see the Issue section of the essay about spatial associations.

This problem is exacerbated by the default behavior of some internet mapping programs and GIS software, namely to randomly locate dots in order to show the number of something like dairy cows within the counties of a state. That kind of default program does not put the well-drained soils on the hilltops; it simply scatters them to whatever coordinates the random number generator happened to assign. In our current home state of New York, computer-generated census maps routinely put thousands of cows on the tops of the Adirondack Mountains, because the programs do not know that most of the farms of St. Lawrence County (the largest in the state, by far) are actually clustered in a fairly narrow strip along the St. Lawrence River in the northwestern part of the county. The rest of the county consists of forested mountains (except to a computer that has a random-number generator to locate cows!)

The prescription for this problem is also similar to what you have read in other chapters – read the metadata for the GIS data file, and learn enough about the system in the real world that you are able to recognize implausibilities when you see them on a GIS map (like the apparent cluster of toxic-waste sites that Cynthia Miller found in the middle of a cornfield on a map of a rural area in Minnesota, because that particular mapping software used a different default procedure and automatically assigned all of the "unknown" addresses to the coordinates of the center of the township).

The bottom line is simply that the most sophisticated pattern analysis in the world cannot come to proper conclusions if some of the key input data have been "mislocated" by well-intentioned workarounds for missing information.

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