Thinking About Spatial Associations

. . . things usually found together, like peanut butter and jelly.

(Drafted 2008, revised 2010 and 2011, update 2015)

This essay deals with organizing and representing geographic information by noting spatial associations among different features. A spatial association (sometimes called a spatial correlation) is tendency for two things to occur together in the same locations – like hot dogs and buns at picnics.

There is a long tradition of using this mode of spatial reasoning in the search for causes of diseases. The "poster-child example" is malaria – people noticed that this disease seemed to occur only in places where a specific kind of mosquito was likely to bite. In other words, the map pattern of malaria is similar to the geographic range of Anopheles mosquitoes. Based on that observation, people could make hypotheses about causal relationships that could then be tested in a clinic. This approach continues to be used extensively in public health, as well as by people studying crime, species extinctions, house values, pollution, and a host of other topics (Mech 1989; Dangendorf et al. 2002; Nunn 2003; Doran and Lees 2005; DeMotto and Davies 2006).

To avoid confusion, we should note right away that people can interpret the phrase "spatial association" in several different ways. To some, it means just the process of mentally linking a feature with a specific place. For example, many people associate the phrase "Baseball Hall of Fame" with a place called Cooperstown, New York. Although researchers often blur the distinction, this simple kind of association is not our main focus in this chapter. In fact, this simple use of the term "association" is really just a synonym for the process of listing the features or conditions at a place; in other words, it is a form of factual recall, not abstract reasoning (see chapter 3).

The focus of this chapter is on a more restricted meaning of the term "association." It deals with the process of observing many features in many places and noting which features tend to occur together, in the same locations, rather than independently, in different locations. This kind of thinking puts great demands on working memory. To think about spatial associations, one must:

1) observe the presence of a particular feature in a particular place,
2) note that another specific feature also occurs in the same place,
3) recall other places where those features occurred together, and
4) recall enough other places to be able to conclude that it is relatively rare for either feature to occur alone (i.e. without the other feature; see Dominey et al.1995).

In short, the kind of spatial association we are exploring in this essay is a "statistical regularity" that we perceive after observing many places, not just a single memory of one feature that we remember as associated with one place (for a careful look at several kinds of statistical regularity, see Turk-Browne et al., two papers, both published in 2008).

This process of discovering statistical regularities can be greatly accelerated by gathering information on the locations of features and displaying the results on maps. In essence, making maps can simplify the task of noting feature associations one at a time, reducing it to a much simpler task of comparing geographic patterns on maps. This is a long and revered tradition in geography (Robinson and Bryson 1957; Lloyd and Steinke 1975). Geographers have developed ways to compare maps mathematically, and to report the results in a summary statistic (e.g., Getis and Ord 1992). GIS software often includes tools for calculating pattern correlation, as well as simply overlaying map layers in order to allow users to make a visual estimate of spatial association. Indeed, of all the modes of spatial reasoning, the process of thinking about spatial associations is the one most strongly supported by GIS software.

Despite the undeniable power of GIS-aided pattern comparison, the available research still seems to say that people remember spatial patterns better from single whole maps rather than individual views of separate layers, tiles, or zoomed-in snapshots, probably because all of those "advanced techniques" require the brain to devote additional effort to piecing together a coherent image. (Bunch 2000).

Research on Thinking about Spatial Associations

One anecdote from the research literature clearly illustrates the difficulties of designing an experiment that unambiguously explores the use of paired-association thinking (Cornell et al. 1987). This experiment involved a toddler, a small room, some candy, and several cups with different colors. Following a carefully prescribed list of steps, the investigator:

- attracted the attention of the toddler,
- placed one or two pieces of candy on the table,
- put cup(s) of a specific color upside-down over the candy,
- put some other different-colored cups on the table as distractors,
- put the rest of the candy away on a shelf,
- identified the "hiding place" of the candy with a gesture toward the table and a verbal statement about the color of the cup(s), and
- released the toddler, with the instruction to "find a piece of candy in its hiding place."

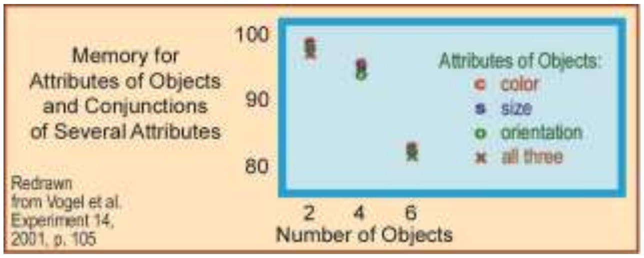
The plan of the experiment was to observe whether the child could identify a cup that contained candy (i.e., could remember the association of the candy with cups of a particular color). When released, the toddler immediately ignored the table, cups, and investigator, and headed directly toward the shelf where the investigator had stored the bag of candy after putting a piece under a cup. If diligently recorded according to standard experimental protocol, that child's action would have to be classified as a failure to remember which colored cup hid the candy – in other words, a negative result! In fact, however, it clearly demonstrates that the child did indeed form a memory of a spatial association between the candy and at least one of its "hiding places," as well as the location of that hiding place. Moreover, the child also showed an appreciation of magnitude – a single piece of candy hidden under a cup was clearly less attractive than a whole bag of candy put away on a shelf. In this way, the child also demonstrates the simultaneous operation of two different modes of spatial thinking – feature association and quantitative comparison (see Essay 5 on spatial comparison; see also Lee et al. 2006).

There is some evidence that thinking about spatial associations has a different learning trajectory than other modes of spatial thinking. For example, 3-year-olds can find something hidden near a distinctive object in a room, but cannot discriminate between two or more identical objects (like, "I know the toy is near a chair, but which chair?"). By age four, however, most children can also use other locational cues to decide which chair is associated with the hidden object (Blades and Cooke 1994; for an extension of this research to include selection of routes, see Allen and Ondracek 1995).

As with other modes of spatial thinking, the process of noting spatial associations appears to be useful in reducing overall memory demands. As far back as the middle 1980s, psychologists were aware that there was a limit to the number of objects that human beings could remember, but somehow people could remember several features of each object without reducing the number of objects held in memory (Duncan 1984; Cowan and Morey 2006). This was generally regarded as evidence that people processed some kinds of sensations in parallel (through different mental channels at more-or-less the same time) as opposed to serially (through the same channel in a sequence, one after the other; see Nakayama and Silverman 1986). Searches for specific combinations of features (e.g., a red cup that is also plastic), however, seem to be conducted serially (Treisman and Gelade 1980). More recently, investigators have refined their techniques and established an even larger capacity for multiple-feature recall.

> "It is possible to retain information about only four colours or orientations in visual working memory at one time. However, it is also possible to retain both the colour and the orientation of four objects, indicating that visual working memory stores integrated objects

> rather than individual features. Indeed, objects defined by a conjunction of four features can be retained in working memory just as well as single-feature objects, allowing sixteen individual features to be retained when distributed across four objects" (Luck and Vogel 1997, p. 279; see also Vogel et al. 2001; Mohr and Linden 2005; Brady and Alvarez 2014)



One big debate has been about whether the learning of spatial associations is *implicit* – that is, an automatic process that is done with little direct attention by the observer. Like many of the debates described in this book, this one had an early flurry of attention by behavioral psychologists in the 1970s and 1980s, followed by a renewed interest by brain-scanning neuroscientists in the early 2000s. For example, one recent experiment concluded that the learning and memory of spatial context

> ". . . are indeed implicit. The results have implications for understanding the neural substrate of spatial contextual learning, . . . The two types of memory [explicit and implicit, also called declarative and nondeclarative] have different characteristics and are mediated by dissociable memory systems in the brain . . . . improved performance in visual search tasks [is] based on [already, and presumably implicitly] learned associations between targets and surrounding visual context" (Chun and Jiang 2003; see also Degonda et al. 2005; Shanks 2007).

Another line of evidence comes from animal studies. In this case, the research involves a surprisingly wide range of species, including squirrels, insects, fish, and birds as well as the more typical rat and monkey studies (see, for example, Jacobs and Lyman 1991; Sovrano et al. 2002; Prior and Onur 2001; Cheng 2005; Dudchenko and Zinyuk 2005). In each case, the animal shows a strong ability to form spatial associations with particular features that may have survival value. This animal research often involves the use of implanted devices that can localize brain activity to within a few millimeters, a resolution that is difficult to obtain with human subjects. As a result, the research raises some significant ethical issues that place constraints on its scope and direction (more about this in the detailed review below).

Few geographers have done well-controlled studies of the process of spatial association, but anecdotal observations tend to underscore that human memory for spatial associations is limited and selective. People have intuitively grasped this fact for a long time, which is one reason why one of the major analytical tools in a modern geographical information system – map overlaying – is designed specifically to assist in remembering and evaluating spatial associations!

The situation is perhaps more hopeful than might be inferred from a quick review of the research. It is possible that the low level of performance on some spatial-association experiments is a result of the kind of maps that were designed for those experiments. In trying to come up with designs that meet specific experimental objectives, including the minimization of the role of prior knowledge as a confounding variable, investigators may inadvertently create maps that fail to include some spatial associations that occur in most real-world maps. As a result, the findings do not provide an accurate indication of how people might perform with real-world maps (Ormond et al 1988;for an example of how this kind of imprecision can adversely affect the results of experiments that are specifically designed to test claims about the separability of different modes of spatial reasoning, take a careful look at Bednarz and Lee 2011).

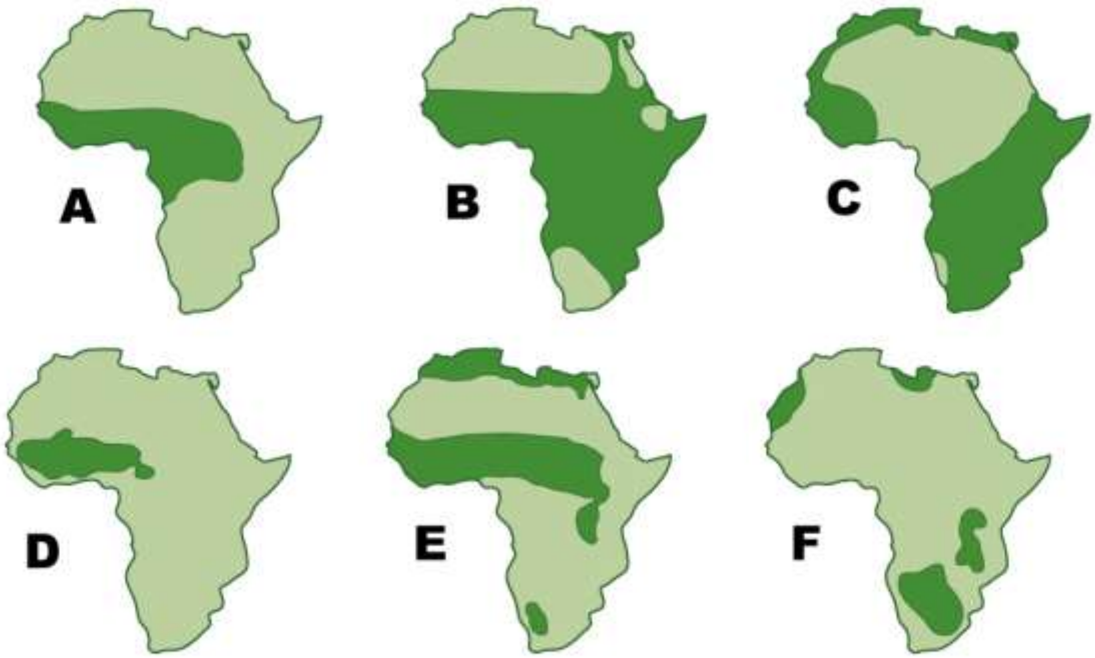
Investigating Spatial Associations: Malaria and Possible Vectors

Dark shading shows where malaria is common.

At first, no one knew how people caught malaria. The word "malaria" means "bad air," because some people thought that you got the diseaseby breathing the air in swamps, dense forests, and other wet places.

The process of discovering the real cause of malaria is a good example of geographic detective work. Part of that research was to compare maps that showed the range of different possible "vectors" (insects or other organisms that might carry the disease from one person to another).

These maps show the ranges of six small organisms that might transmit malaria to humans.



Which three organisms shown on the maps above are the <u>least</u> likely to be responsible for transmitting malaria to humans? Circle their names:

A. Chrysops (mango fly)	B. Anopheles (mosquito)	C. Ornithodoros (tick)
D. Simulium (biting fly)	E. Phlebotomus (sand flea)	F. Xenophylla (rat flea)

Which one is the most likely? Why?

Sample dialogs, from two teachers trying to teach about the spatial associations between cotton plantations and environmental characteristics

T: Today we are going to look at the environmental context of large plantations before the Civil War. As you may know, people did not build big plantations with hundreds of slaves in all parts of the South. Most parts of the South did not have large plantations. In fact, people in some places actually fought on the side of the North in the Civil War, because they did not want to defend slavery. Look at the map of large plantations. What do you see on this map?

S: The dots seem to be kind of bunched together

T: Right. Now keep the position of those bunches in mind and look at the other map. How would you describe the areas where the big plantations were? S: all along the coast of South Carolina.

T: Good. Can anyone describe the location of another cluster? . . . .

T: This map shows large plantations, ones that had hundreds of slaves, and this map shows natural environments. What environments are geographically associated with large plantations?

S: How are we supposed to tell?

T: Try this: turn your eye into a sampling machine. Look at a specific place that has a lot of dots on the plantation map [gesture]. Then look at exactly the same place on the other map, and see what environment is there. Repeat for some more places [gesture].

S: OK, it looks like there are a lot of dots in the Sea Islands area.

T: Good. Just to be sure we all know, what state is that in? S: South Carolina

T: Good. Now, has someone else found another geographic association?

S: Something called the Selma Chalk region in Alabama? What's that?

T: It's a soft rock that makes a very fertile soil. Why would that be good for plantations? . . .

These dialogs illustrate what should by now be a familiar refrain – the difference between a lesson that reinforces a specific mode of spatial thinking and one that does not can hinge on a single phrase or question – in short, "the devil is in the details," and the details are cumulative

The two dialogs are the same length (155 words). The first one, however, has partially removed the "aha" from the map activity by asserting the conclusion at the outset, before students have had a chance to look at the map. The second one delays the conclusion in order to focus on one small but important part of the process of map comparison – the selection and use of sample points in specific places, rather than simply making a broad visual snapshot of the entire map.

We think there is a place for both kinds of activity in a classroom – in other words, teachers are free to make decisions about the focus for a particular lesson. Some lessons should simply try to transmit facts in an interesting and efficient way. Others should help students acquire skills.

But since this is a book about spatial thinking, we'd like to emphasize that we think students are shortchanged by classes that use maps only as visual illustrations of verbal points that the teacher has already made. It is admittedly hard, especially at first, to use maps as the primary vehicle for making a point – in other words, to force students to perform some of the "hard work" of spatial thinking. But the payoff comes when students master the skill and can apply it in other situations. Moreover (and this is a really important point), the second dialog can help students understand what goes on "under the hood" when a GIS does a map pattern correlation.

Additional student activities that involve thinking about spatial associations

Most of the statements about spatial associations in the sample dialog are simple qualitative observations, but the same basic procedure is used in quantitative comparisons:

- find a point on one map,
- note the value at that point,
- find the same point on the other map,
- note the value there,
- repeat steps 1-4 for a statistically valid number of sample points, and
- tabulate or graph the relationship.

Both kinds of spatial associations – qualitative and quantitative – can occur for different reasons. In the course of their education, students should do inquiries that help them recognize the difference between spatial associations that occur because of:

1. direct causal relationships, like a case of malaria caused by the bite of an infected Anopheles mosquito. Examples that students might be led to "discover" can range all across the scale continuum. Local examples include worn spots on rugs where foot traffic converges on a door, or shadows associated with clouds seen from an airplane. [Insert Fig 12-2 here]

   At a global scale, petroleum occurs in association with particular kinds of rock, and earthquakes usually occur near plate boundaries ("The Earth Moves" in Malone et al. 2005, p 61ff). One important spatial association that primary-school students should discover is between rivers and elevation, how rivers start in relatively high places and flow downhill. Middle-school students can begin to explore association of particular animals with particular plants or other animals. At a local scale, particular birds or insects tend to nest in particular kinds of trees. At a continental scale, the mapped ranges of predators like lions often resemble the maps of impala, zebra, and other prey species (a situation that lions no doubt find more congenial than impala do).
2. indirect causal relationship, in which two features are best interpreted as consequences of a third condition in a place. Examples include snow, permafrost, and polar bears in cold places, or lawyers' offices, bail bondsmen, and coffee shops near courthouses. The distinction between direct and indirect causation can be difficult (see the issues section below), which is one reason why students should explore several examples and discuss their observations. The CD folder has maps and photos that can be used as illustrations.
3. transportation-related associations, which are a subset of indirect causal relationships that are especially important in applied geography. Examples include clusters of motels, gas stations, and restaurants near rural freeway exits; associations of factory locations with the route of I-85 in South Carolina; or the clustering of container railyards, warehouses, customs houses, longshoremens' union offices, hotels (and red-light districts!) near ports.
4. negative associations, where the presence of one feature virtually guarantees the absence of another. Examples include wealthy neighborhoods and sewage treatment plants, igneous rocks and petroleum, or particular kinds of government and women's rights.
5. "temporary" or "accidental" associations that can be explored with a GIS, e.g., by tabulating the areas flooded by the storm surge from a hurricane such as Katrina.

Students should be encouraged to formulate hypotheses and test spatial associations for a wide range of topics. The best way to do this is also the simplest – make a point of modeling the process often, "as part of your normal thought process," so that they get the hint and do it themselves. Don't just show a map of the extent of the Roman Empire, point out how many of its borders were associated with wide rivers that were difficult for soldiers in armor to cross. Don't just mention that nomadic people are moving into settled areas in Darfur, show maps that illustrate the association of particular kinds of land use with rainfall, and discuss the effects of drought on land-use patterns. In short, use spatial association (and pattern, aura, region, etc.) as a teaching aid.

Detailed review of research on thinking about spatial associations

As with other modes of spatial thinking, such as shape or pattern recognition, the development of competency in spatial association is greatly aided by the acquisition of relevant language. In one study, for example, toddlers could find a hidden treasure near a wall that was painted with a particular color, but performance was much better if the child had already acquired words such as “blue” and “adjacent” or “next to” (Hermer-Vasquez et al. 2001; see also Twyman et al. 2007). In other words, the children seem to have the mental capacity for spatial association prior to the acquisition of language, but the application in a particular instance is greatly aided by the availability of suitable words. “Much like the relation between constraints governing analogical reasoning . . . the true relation between iconicity, associations, polarity, and structural similarity may be additive, pragmatic, and hierarchical” (Gattis 2001, p 243). Moreover, people seem to be able to make some quick observations in a particular landscape and subconsciously infer from them whether it makes more sense to focus on spatial associations or overall structure (Stankiewicz and Kalia 2007). Whether that personal-scale skill also applies to geographical scales is an unanswered question.

Meanwhile, an important study about child language came to a conclusion that provides justification for something that good teachers have done for a long time – namely to show multiple instances of a landscape feature (e.g. a desert oasis or Victorian house) rather than a single “perfect” example. That time-tested pedagogical tactic turns the learning task into a process of extracting the common features of several examples. This yields a better grasp of the concept and a more durable memory than is likely to form when we try to learn all of the potentially relevant traits of the perfect example (Ross et al. 1986). This is especially important in learning sub-parts of a scene (Boyce et al. 1989; compare Winograd and Church 1988; Chun 2000; Hribar et al. 2012; for a look at the role of language in mediating associative memory, see Dessalegn and Landau 2008).

When looking at feature conjunctions, however, the research picture is less clear. On the one hand, a novel association of features tends to attract attention, and for that reason “scene-inconsistent” objects may sometimes be remembered better (Brewer and Trevens 1981). On the other hand, there are advantages to consistency in presentation, and research clearly shows that “memory performance was more accurate when the test alternatives were displayed within the scene at the same position originally occupied by the target than when they were displayed at a different position” (Hollingworth 2006, p58; for an intriguing link with the process of learning how to read, see Gennari et al 2007).

In some other research subfields, the main conclusions about spatial associations seem almost too obvious, but they are nevertheless important and, unfortunately, all too easy to forget. For example, spatial associations are easier to see in places where prominent features are clearly spatially associated (Cubucku and Nasar 2005; Travis et al. 2013). Here is a “practical” example: seeing a school-crossing sign triggers a memory of the spatial association of similar signs with dangerous intersections (and with lower speed limits, greater police vigilance, and an associated risk of a speeding ticket if driver behavior does not change after viewing the sign!) That association, in turn, is likely to be linked with a memory of analogous spatial relationships in other places. Here is a simple statement of the analogy as it might be perceived by a driver: *sign* is to *where I am now* as *school crossing* is to *about 300 feet ahead of me*. If, however, the officials in a particular city put signs at widely varying distances from the school crossings, drivers will not form as clear an impression of the spatial association between signs and crossings, and the ability of the signs to influence behavior is compromised (I have to admit that I have the traffic ticket to prove it!)

Despite the obvious everyday importance of associative memory, the brain-scanning research still seems ambiguous. (Warning – that sentence probably means that a couple of hard-to-read paragraphs are coming!)

> “Associative recognition and recall depend on structures in the medial temporal lobes (MTLs). There is disagreement about whether associative memory is functionally

> heterogeneous, whether it is functionally distinct from intra-item associative memory and how the MTLs contribute to this kind of memory" (Mayes et al. 2004, p 127; compare Day et al. 2003; Ji et al. 2003; Howard et al. 2005; Law et al. 2005; Miranda and Bermudez-Rattoni 2007; van Kesteren 2010; Wang et al. 2012).

Even the simplest association, the link between an object and a location, is neurologically complex:

> "we found the bilateral posterior PHC to participate in encoding of both the object associated with a location and the location associated with an object. In contrast, activity in an area in the left anterior PHC and the right anterior MTL was only correlated with the memory for the location associated with an object" (Sommer et al. 2005, p343; Aminoff et al. 2007; Andersom et al. 2008; Bachevalier and Nemanic 2008; Crespo-Garcia et al. 2010; Libby et al. 2014; for recent discussions of how associative memory helps wayfinding, see Mallot and Gillner 2000; Renaudineau et al. 2007; Nardini et al. 2008; Navawongse and Eichenbaum 2013; Lingwood et al. 2014; van Buuren et al. 2014); for a suggestion of a biologically plausible way of fast coding of feature associations, based on the idea that neurons may be sensitive to the spatial organization of their inputs, see Elliffe et al. 2002; for a discussion of brain changes that accompany consolidation of associative memory, see Takehara-Mishiuchi and McNaughton 2008).

The picture becomes even cloudier when we extend the idea of association to include the conjunction of features (the tendency of multiple features to occur together in a particular location).

> "The IPS junction with the transverse occipital sulcus and the FEF responded at a higher amplitude during conjunction search. Moreover, regions of the prefrontal cortex and the PPC were activated only during either hard feature or conjunction search. These findings suggest that equally difficult visual searches for features and conjunctions are controlled by overlapping frontoparietal networks, but also that both search types involve specific mechanisms" (Donner et al. 2002 p 16; Chua et al. 2007; Freiwald 2007).

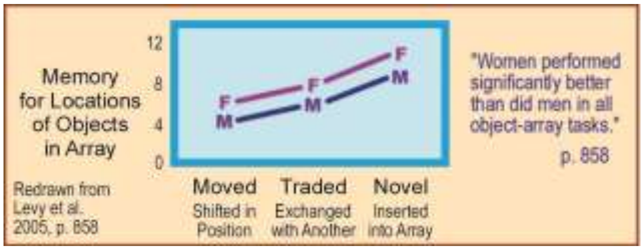
> "Simple features of objects are represented caudally and feature conjunctions are represented rostrally" (Buckley and Gaffan 2006 p 103; for some research that used a radically different technology, selective chemical lesions, in order to study paired-association memory formation, see Lee and Solivan 2008; for other recent reviews, see Giovanello et al. 2009; Hannula and Raganath 2008).

To complicate matters even further, it appears that temporal associations are encoded via overlapping and occasionally interchangeable pathways (deRover et al. 2008). Moreover, lesions to the parietal cortex on the side of the head can affect some kinds of associative information (Rogers and Kesner 2006). Finally, there is some evidence of a developmental trend in brain organization through childhood and perhaps into adolescence, with higher-order association cortices maturing later, after lower-order somatosensory and visual cortices (Gogtay 2004).

After wading through a few paragraphs like those, it is important to take a deep breath and to note, with gratitude, that one does not really need to have any great knowledge of brain anatomy to get one important take-home message from these studies: *the human brain seems to do different kinds of spatial associations in different places, with different links to long-term memory*.

This fact raises the possibility of neurologically caused individual differences in the ability to perform spatial associations at different scales. That recognition, in turn, leads to one of the really messy questions in this entire field of inquiry. One cannot end an essay that deals with thinking about spatial associations without at least acknowledging some research findings that are, to put it mildly, somewhat controversial – namely that differences in performance on spatial-association tests may have a genetic basis that is linked to the X-chromosome and therefore to sex hormones. In general, males tend to outperform females on tests of mental rotation and wayfinding (Sholl et al. 2000;

Roberts and Bell 2003; Kempel et al. 2005), but females generally perform better than males on tasks that involve memory for objects, locations, and spatial associations, such as the perception of changes in what one research team calls "arrays" of objects (Levy et al. 2005; see also Sandstrom et al. 1998; Leibeck et al. 2009; these differences, however, may apply only to realistic pictures, not really abstract symbols – see Choi and l'Hirondelle 2005).

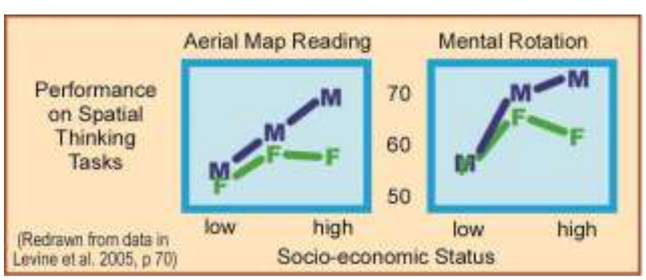


This book is not the place to attempt a definitive review of what has become a very large body of research about sex differences in spatial cognition. Suffice it to say that a number of thoughtful people have come to the conclusion that sex differences in performance on certain spatial tests may be related to the gene-selective influence of sex roles in hunter-gatherer societies. In simple (and therefore possibly misleading!) terms:

- hunters in a society would have a selective advantage if they had superior spatial-sequencing ability, so that they could find their way back home after a long chase, whereas
- gatherers would have a selective advantage if they had strong spatial-association skills, so that they could remember which landscape features are associated with particular kinds of food; for example, which trees, seen from afar, are likely to have specific fruits at specific times, or edible mushrooms growing under them, or honeybees nesting in them, and so forth.

To the extent that hunting and gathering roles were assigned to specific age-sex groups, one might expect that these selective pressures could eventually lead to sex-linked differences in performance on specific kinds of spatial thinking (Silverman and Eals 1994; Voyer et al. 2007; Ineke and Borst 2011; for a summary of evidence for such a genetic connection, see McBurney et al. 1997; for a suggestion that the difference may involve a tradeoff that depends on learning trajectories, see Woollett and Maguire 2009. In a fascinating replication of a rather dry find-your-way-in-a-museum study, several researchers noted a strong female advantage in quickly learning the associations of specific foods with specific features in a complicated grocery store, and that the mean error in pointing (after just a single training tour!) was dramatically lower for high-calorie sweets and nuts than for low-calorie salad items - see New et al. 2007. Readers interested in even more speculations are encouraged to use the keywords "hunter-gatherer hypothesis" in a web search to get more perspectives on this question.)

Meanwhile, I will simply end this essay by repeating that the process of thinking about spatial associations is complex, multi-faceted, and important. And, like many other things where there may be a significant genetic influence on "innate" ability, the record usually shows that environmental conditions (including both formal and informal education) are usually more important as determinants of actual performance. In this particular case, the research also shows that "socio-economic status modifies the sex difference in spatial skill" (Levine et al. 2005, p841).



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

One important overlap appears to be scale-dependent – what looks like a spatial association at a continental scale may be viewed as an analogy at a local scale. As some vision researchers said,

> "objects have a tendency to occur in particular positions and in particular spatial relationships with other objects. If the visual object recognition system maintains position frequency information, it can be used as a constraint to aid in the recognition of ambiguous or occluded figures" (Kravitz et al 2008, p. 120).

For example, at a personal scale, one might observe that particular birds tend to makes nests at particular distances above ground in particular kinds of trees; newspaper boxes occur in rows on sidewalks next to subway entrances; fishkills occur just downstream from pollutant inflows; seedlings of some flowers germinate more successfully in the shade of specific trees; etc. On a map of a larger area, however, those particular combinations of features simply appear to occur "together, in the same locations" (like peanut butter and jelly, which usually occur together in the same room, and often between the same two slices of bread!)

Another logical overlap occurs because of the way in which we often "discover" a spatial association, namely by overlaying and comparing two maps that show the regions (spatial extent) of something like Anopheles mosquitoes or malaria. As if that weren't confusing enough, the chapter on spatial patterns noted that the thing we notice when we compare regional maps is often the visual similarities in the spatial pattern of the features on the map.

Once again, the key to making a distinction between various modes of spatial thinking is to ask neuroscientists whether the processes involve specific regions of the brain, with their separate sets of connections with other brain areas such as working and long-term memory. When we do that, we see that a typical phenomenon of the real world, such as the association of mosquitoes and malaria, can be learned through different kinds of spatial (and non-spatial) thinking:

1. we can accumulate enough location-referenced observations of mosquito bites and sickness to form an impression of a spatial association, or
2. we can mentally overlay regional maps and estimate the degree of overlap, or
3. we can compare map patterns and notice the similarity, or
4. we can subject people to experiments in which they expose their arms to mosquitoes and wait to see if the disease develops.

In short, we learn about the world in different ways, and some of these ways involve various modes of spatial thinking. Neuroscientists have monitored the brains of people doing these and many other kinds of thinking, and they have identified specific areas of the brain that become engaged when people deal with spatial comparisons, patterns, sequences, associations, and so forth.

So let's ask a question that we also asked in the essay on spatial analogies: are the shadows spatially associated with the clouds in this picture, or is each shadow in an analogous location with respect to a cloud, or are there regions of clouds and clear sky in the picture? Like the muscles in your arm, you use different modes of reasoning to ask different questions about a scene.

Issues with using a GIS to support thinking about spatial associations

This essay has noted that spatial association is a distinctive mode of spatial reasoning, and that a typical GIS can serve as a valuable, and in some cases irreplaceable, support structure for this kind of reasoning. One obvious reason why GIS has this capability is because it can store enormous amounts of georeferenced information and display it for easy comparison of geographic extent. A more subtle but perhaps even more important reason is that a good GIS can perform a number of tasks that make it much easier for humans to compare spatial patterns and to assess the extent to which two different phenomena seem to occur together, in the same places. These tasks include rescaling maps of different sizes, adjusting perspective of maps that have different orientations, reprojecting maps that were drawn with different coordinate systems, and so forth (see Downs and deSouza 2006, p 149 and surrounding pages for a complete list).

The potent transformational capability of a GIS makes it especially important to consider the same issue that we discussed in the essays on spatial regions or spatial patterns, namely that the scale and precision of the original gathering of data has a powerful effect on the reliability of an estimate of spatial association on transformed maps. The safest kind of conclusion about spatial association is one based on what Brown and others called "punctual relationality," namely the gathering of each kind of information from exactly the same individual person or point in space (Brown and Gersmehl 1987). Unfortunately, when we have to rely on multiple sources of information, that kind of spatial precision in data gathering is the exception, not the rule. Weather information for a place, for example, is usually interpolated from a relatively sparse network of observation stations (or inferred from indirect measures as seen from a satellite, yet TV weathercasters confidently assert that the temperature in a particular city is exactly NN). Similarly, demographic and economic data are gathered and summarized for relatively large areas such as census tracts and minor civil divisions. Other data may come from

- questionnaires administered to different random samples of people,
- water samples that were taken at different depths and times of the day,
- soil maps that were compiled from mental landscape models, supplemented by occasional soil samples, and
- satellites that passed over the site at a specific time of day, perhaps a week ago (or maybe that day was cloudy, and the satellite had its last clear view several months ago),

Yes, the data situation is getting better in many ways, aided by better technologies such as side-looking radar or GPS satellites. Here is a useful exercise for anyone who thinks that something like GPS has ended spatial uncertainty. That person should look at the Google Earth photos that people have submitted for a place like Easter Island and marvel at how many different geographic locations are associated with pictures of the same photogenic row of huge stone statues!

Focusing on these obvious data problems, however, can mask a more subtle but potentially even more troublesome issue, namely that at some scales it is difficult to map some kinds of features <u>without</u> using the concept of a spatial association. Soils, for example, are notoriously difficult to map at a state or even a county scale, because relatively small patches of radically different soils tend to occur close to each other in most landscapes. The compromise solution is simply to map the soil associations of the county ("association" is, in fact, the official term used by the Natural Resources Conservation Service, and one that has been used for this purpose for decades). A soil association is defined as a repetitive juxtaposition of dissimilar soils in predictable locations in a variable landscape.

Here is an example. Our farm in western Wisconsin is part of a stream-dissected loess plateau. The broad hilltops have a deep and fertile soil that is called Seaton, because it looks more like a soil first described near Seaton, Illinois, than any other named soil in the "official" list. The gentle slopes on our farm have a thinner soil called Dubuque. The steep side slopes have even more rapid erosion and therefore a shallower soil called Dunbarton. Finally, the valley bottoms have a thick but flood-prone soil called Chaseburg.

You don't need to memorize these names – there are thousands of different kinds of soil. What you do need to remember, for a few minutes, is that our part of Wisconsin is mapped as Seaton-Dubuque-Chaseburg association. Tell that fact to some soil scientists, and they can immediately conjure up an image of the land that is accurate enough that they can make reasonable crop and engineering recommendations to anyone who asks about a particular field. But try to assign a single value for "soil productivity" or "erosion risk" to that area, and the innate heterogeneity of the association makes your number meaningless. For example, Seaton soil can produce 180 bushels of corn per acre in a good year, whereas the yield on Dubuque soil is much lower because of inadequate root depth. Meanwhile, Dunbarton is so thin and rocky that no sane farmer even tries to plow it, and Chaseburg almost as productive as Seaton, except in rainy years when floods can destroy the crop.

Here, we would very much like to say, "obviously, one cannot simply construct a data table that contains numbers showing the crop yields, land values, or erosion risks for a state-scale map of soils." Unfortunately, people do make those kinds of tables. Moreover, unwary users often use those data as if they were measures of some relatively "pure" phenomenon. The result is significant risk of great error – like zoning my farm as unsuitable for septic tanks because the general soil map clearly shows that the dominant landform for this part of the county is a steep slope with a thin soil over bedrock (when in fact the only place on my farm where I would try to build a house is on the level hilltop land where the deep Seaton is almost ideal for septic tanks!)

Fortunately, a knowledgeable GIS user is often able to use other data tables in the GIS to "improve" the soil data for specific purposes. For example, one can use a fine-grained digital elevation model (if available) to produce an estimate of local slope, and then use that slope "measure" to select which of several soils in an association is most likely to occur on that specific site.

This lengthy example has underscored a major point about the use of GIS to aid spatial thinking – prior knowledge of the system you are considering is helpful in avoiding common misperceptions that can occur because different kinds of data have different inherent characteristics that lend themselves to different kinds of display at different scales.

The dilemmas get even knottier when we are dealing with sensitive information about individual people – data about finances, religion, medical conditions, and so forth. In this arena, some kinds of data are deliberately "masked" in order to preserve the privacy of individuals. This is done for partly humane and partly pragmatic reasons – there are legitimate concerns that if the rules were relaxed, people might be less willing to provide information, and we would actually be worse off (Kwan et al. 2004).

We will leave it to another book (perhaps by another author!) to continue this discussion by looking at the origin and propagation of error that arises due to faulty interpolation, extrapolation, normalization, or other attempts to discern spatial associations among phenomena that are observed and tabulated in different ways. Suffice it here to say the mere fact that a GIS can combine data files quickly and almost automatically does not reduce the potential for error if someone combines a "pure" data set, such as ownership or political jurisdiction, with a "mixed" or "association" data set such as a map of soils.

It may make sense to view this as yet another manifestation of the "ecological fallacy," as described near the end of Essay 5. Here is a quick summary –

1. Map A shows that per-capita income is very high in neighborhood X, low in neighborhood Y.
2. Map B shows that many people work in neighborhood X as domestic servants and gardeners, while few people hold those jobs in neighborhood Y.

3. Putting those maps together, we might reasonably (but wrongly!) conclude that domestic servants and gardeners must have high incomes.

This kind of "logic" happens often enough that we should repeat, for emphasis, that the demonstration of a spatial correlation between two phenomena does not prove that one causes the other. Here is a useful classroom example. It is an easily demonstrated fact that the geographic coordinates of sick people, injured people, and recent deaths tend to have a high degree of spatial association with the locations of hospitals. It would be a fallacy, however, to observe that spatial association and come to the conclusion that hospitals cause disease, injury, and death. Admittedly, this is an absurd example, but we would strongly recommend that teachers make a big deal out of an absurd example like that early in a course, so that it is available as a shared memory to be invoked later, when people students, newspaper editors, TV commentators, or others commit the same error with more controversial topics:

Do graffiti on apartment walls cause crime?

Do high taxes drive business away from a state?

Do large tractors cause soil erosion?

Do particular religions breed terrorists?

Does the death penalty really deter murderers?

Do generous welfare payments attract lazy immigrants?

. . .

Do hospitals cause sickness, injury, or death?

Are domestic servants wealthy?

Bottom line: It is not hard to show that all of the pairs of features on this list are spatially associated. Demonstration of spatial association does not prove causation. It can, however, be an exceptionally powerful tool for suggesting hypotheses that might be worth investigating.

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