Chapter 2 – Thinking About Location

You are here, . . . relatively speaking.
Drafted 2008, revised 2010, mild update 2015

The idea of location is the "entrance ticket" to a geographic discussion – it is the identifying feature that makes a question geographic (as opposed to historic, literary, musical, etc.).

Here is a simple example to illustrate the distinction. A melody and its accompanying harmonies are entities that a musician might analyze. Once a tune has been played or heard in a specific location, however, it becomes a geographic fact, and therefore a possible topic for geographic inquiry. Likewise, a tree is a biological entity – a tree on a specific slope of a mountain is a geographic fact.

If the location of a feature is not part of the discussion, the inquiry is probably not geographic.

In this context, it is very important to note that human brains do not seem to have any structure that observes and stores information about location *per se* (Eichenbaum et al. 1999). On the contrary, the brain must always determine and describe location "on the fly" by using other spatial-thinking skills.

This book is about the parts of the brain that "light up" when people think about spatial relationships – when they point to objects, estimate distances, compare magnitudes in different places, identify clusters of features, recognize spatial patterns, and so forth. The table below is a kind of "appeteaser" – it cites a few key studies (roughly one from each essay) that show how the so-called "fundamental concept of location" is really derived by applying other, very specific kinds of spatial thinking.

Locational expression	Brain "Region"	Researcher(s)
association with a landmark	ventral occipitotemporal cortex	Bohbot et al 2004
part of a cluster of features	intraparietal sulcus	Kadosh et al. 2005, 2008
proximity to boundary or object	medial entorhinal cortex	Solstad et al. 2008
enclosure in a visual region	posterior parietal cortex	Corbetta et al. 2000
status in a hierarchy of areas	medial temporal lobe	Burgess et al. 2001
position in sequence of locations	dorsomedial frontal cortex	Histed and Miller 2006
analogy with another location	lateral prefrontal cortex	Bunge et al. 2005
directional orientation of a line	ventral extrastriate cortex	Ng et al. 2001
categorization of object shape	ventrolateral prefrontal cortex	Schendan and Stern 2007

You do not need to know much about brain anatomy to get the first big "take-home" message: different kinds of spatial thinking seem to take place in different parts of the brain. This raises the possibility of individual differences in student ability to use different kinds of spatial thinking.

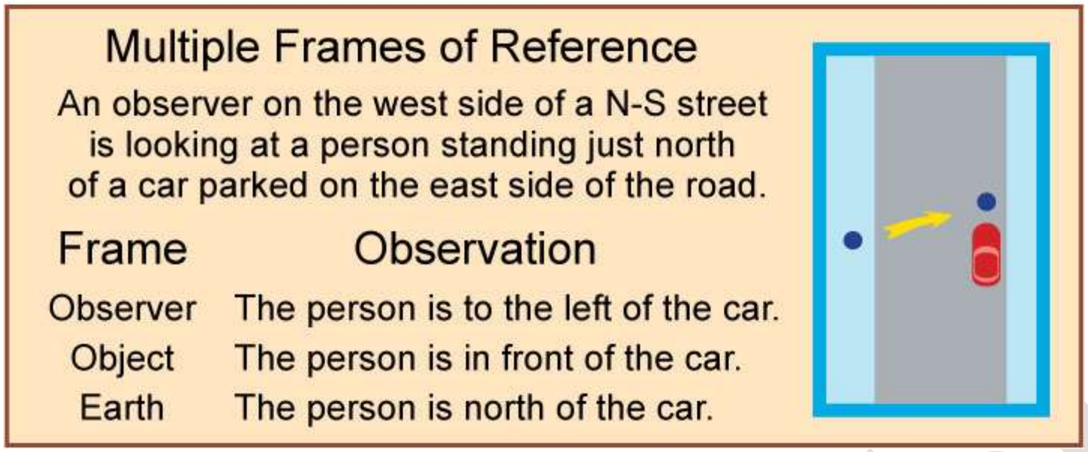
The studies noted above are just a tiny fraction of more than 4,500 research reports that we reviewed while writing these essays. In addition to posing questions about the possibility of neurologically based individual differences, this mass of research has other implications for geography teaching.

One obvious "casualty" is the distinction between *absolute* and *relative location*, which many geographers use for pedagogical purposes (and, alas, have been enshrined in the National Geography Standards and many state standards). Brain research provides no support for that distinction:

> "The concept of location is inherently relative. One cannot describe the location of an object without establishing a frame of reference. For example, to describe locations on the surface of the earth, we customarily use coordinates of latitude and longitude. Just as frames of reference are required to specify location and orientation in physical space, human memory systems must also use frames of reference of some kind to specify the remembered locations of objects" (Mou and McNamara 2002 p162; note especially that the example they use to illustrate how location is relative is the same example that the National Geography Standards cited as an illustration of absolute location!)

Bottom line: *all locations are relative, and human brains think about location in many different ways*.

PS. And Kant was right: brains are "hard-wired" to organize knowledge spatially (Palmer and Lynch 2010).



Research on Thinking about Location

This essay started by noting the importance of location as an "entrance ticket" to a geographical insuiry. The introduction ended with a long quotation about multiple relative frames of reference. That 2002 statement was based on behavioral-psychology studies, but it received a solid vote of support with several brain-scanning studies published two years later. The results of one study were deemed so important that they were stated in the title, where even a casual reader of a bibliography could not miss the point: "Reference frames for spatial cognition: different brain areas are involved in viewer-, object-, and landmark-centered judgments about object location" (Committeri et al. 2004).

That brain-scanning study (and many others like it) provide a solid neuroscientific foundation for three conclusions that many psychologists had already drawn on the basis of behavioral experiments:

- the human brain uses a number of different frames of reference,
- it uses those independent frames of reference more-or-less simultaneously, and
- it does so from very early childhood, far sooner than implied in the "stages" of development suggested in the middle of the last century by Piaget and Inhelder (1956).

In fact, "there is no evidence for a default frame of reference in terms of initial response tendency" (Allen 1999, p 426; see also Woodin and Allport 1999; Postle and d'Esposito 2003; Taylor and Rapp 2004; and Surtees et al. 2012). Many of these authors acknowledge that there is plenty of evidence for improvement in the use of different spatial frames of reference over time, especially between the ages of 3 and 8, but they usually conclude that "during childhood, these constructs apparently co-exist in parallel, and in task situations they may be assumed to be activated simultaneously" (Allen 1999, p 427; see also Nadel and Hardt 2004; Crescentini et al. 2014).

In short, "allocentric representations of object locations relative to environmental cues probably exist in parallel to egocentric representations of location relative to the subject" (Burgess 2008 p83; Aavramides and Kelly 2010; Derdikman and Moser 2010). Those allocentric representations, in turn, appear to fall into a number of qualitatively different groups, including (but not limited to):

- relative position with respect to a landmark (proximity),
- relative position within a larger area (enclosure, or hierarchy),
- relative position along a gradient of some kind (sequence, transition),
- relative position as part of a group of similar objects (region),
- relative position in a non-random arrangement of objects (pattern),
- relative position that is consistently near another particular kind of feature (association), and
- relative position that can be described as similar to the position of another known object in a different part of the world (analogy).

These location concepts form the basis for this entire project – we will devote a separate essay to exploring the neuroscientific underpinnings and educational implications of each one.

> (Hidden inside that sentence is an important message – readers should not worry if the distinctions between various modes of spatial thinking are not completely obvious in the ultra-concise lists we put in this introductory essay. If we could adequately treat an idea in one page, why would we need to write a book?!
>
> Restating that fact, however, gives us one more opportunity to repeat our major, namely that brains are different, and awareness of the likelihood of individual differences in brain structure and function is important in designing educational materials and assessments).

A multitude of locational vocabularies

The takehome message so far is that human brains appear to "think" about location in different ways, using different brain structures and/or networks. This idea is obviously important, but it is so abstract that it provides little guidance for teachers in selecting, adapting, and using educational materials in the classroom. One way to make the idea more concrete is to explore some of its real-world consequences.

Here is one obvious consequence: humans have developed quite a large number of different ways of expressing locations to each other. These "locational vocabularies" reflect the fact that we conceive of location in different ways when we are in different settings or need to describe locations for different purposes.

Some of the student activities described in this chapter are designed to explain and employ a number of these locational vocabularies. These activities provide good examples of the kinds of features that each vocabulary is particularly good at expressing. For example, air traffic controllers can describe airplane locations efficiently and accurately by using an airport-centered system of mathematical coordinates that specify the cardinal direction and distance to each plane.

That kind of system would not be appropriate as a way to explain how to find a particular book in a library, or to deploy defensive backs in a zone to guard against a sideline pass on a football field. In short, any list of useful locational vocabularies will include some vernacular as well as "scientific" expressions of location.

At the other extreme are the highly specialized locational vocabularies that are used when locational information is translated into digital form for storage, analysis, and display. We will address some questions about this practice near the end of the chapter. All of these questions emerge as a logical consequence of the main point mentioned above: the human brain does not have any structure that observes and stores information about location per se.

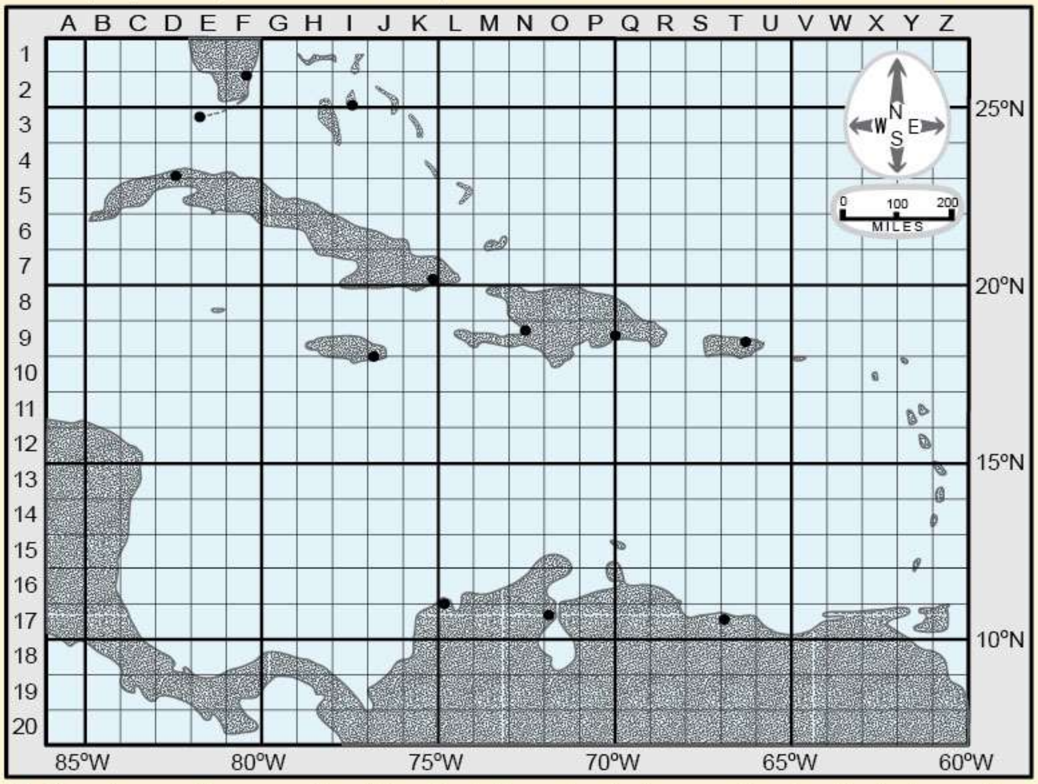
In sum, a large number of researchers have used various kinds of brain-scanning technology to see what parts of the brain become involved when people address different kinds of tasks, such as:

> estimating the harvestable volume of a forest stand
>
> tracking the migration of caribou around an oil platform
>
> sending emergency vehicles to the site of a potentially explosive fire in a chemical warehouse,
>
> tracing the spread of a communicable disease, or
>
> estimating the potential number of attendees at a music concert.

Each of these tasks requires a different set of spatial-thinking skills, which in turn seem to make use of different structures in the human brain.

Where is the Pirate?

Cuba is long; Hispaniola big; Jamaica to the west; Puerto Rico to the east; Trinidad near South America.
Major cities: Miami and Key West in Florida, Nassau in the Bahamas; Havana and Guantanamo in Cuba;
W to E: Kingston, Jamaica; Port au Prince, Haiti; Santo Domingo, Dominican Republic; San Juan, Puerto Rico;
Barranquilla, Colombia; Maracaibo and Caracas, Venezuela. The islands in a N-S string are the Lesser Antilles.



1. Two players sit on opposite sides of a table and put a box or other barrier between them to make it impossible for either player to see the paper in front of the other player.

2. The Pirate chooses a grid square and puts a cardboard marker or small ship symbol in it.

3. The Searcher asks a location question. That question must use at least one longitude, latitude, row number, column letter, direction, island name, or city name. Examples:

Are you in map grid column M? Are you west of 75 degrees longitude?
Are you close to Panama? Are you south of Jamaica? Are you between Cuba and Jamaica?
("South of Jamaica" means in map columns H, I , or J and rows 10 thru 20.)

4. The Pirate must answer yes or no. If no, then the Pirate must add a correct statement that uses a different way of expressing location. Examples:

No, I'm east of Kingston. No, I'm in Grid row 8. No, I'm south of 20°N latitude.

5. If the answer to the Searcher's question was No, the Pirate is allowed to move one square horizontally, vertically, or diagonally (2 or 3 for a more challenging game).

6. The Searcher can then ask another question. This question must use a different way of expressing location than the Pirate used.

7. Continue asking and answering questions until the Searcher finds the Pirate. Count how many questions it took to find the Pirate. Then trade roles and repeat. The winner is the one who finds the other person with the fewest total questions.

Sample dialogs, from two teachers trying to teach some basic placenames

S: (to another student) This placename worksheet is really boring – color me red, color me blue.

T: (overhearing) I agree. It's just background for looking at issues in those places.

S: So why don't we find a better way?

T: OK, how about turning part of it into a kind of rap. You know,
Uruguay is small and round, hey
Paraguay is twice as big,
looks like a pair o' guays
Argentina's lean an' mean-a
But Chile is rilly skinny.
Whaddayathink?

S: It's kind of lame, but

T: Right. It's better than coloring boxes. You wanna try writing one? What would you say about Peru? That it looks like a capital P? Ecuador's right on the equator?

S: (to another student) This placename worksheet is really boring – color me blue.

T: (overhearing) I agree. The problem is, it uses only a tiny part of your brain. But our real goal is to look at issues, like pollution or migration. So, think about this. If you put some junk into the river here (points), what country is it in now?

S: Looks like Peru

T: Right. Near Cuzco, where the Incas lived. Now, if it flows downstream, who gets it next?

S: Bolivia? T: and then? S: Brazil.

T; Good. Now, try another perspective – if a bomb went off here, and winds blow from the east, who gets the radiation? Keep going that direction for awhile.

These dialogs illustrate two different ways to get over a common hurdle. Both are appropriate in some settings, because everybody faces this challenge.

The two dialogs are the same length (110 words), but the second one sets up an inquiry scenario instead of a simple memorization task. It also puts placenames into a context that is harder to dismiss as irrelevant – especially if the teacher has plenty of anecdotal knowledge about current affairs to mention at appropriate times.

Neurologically, the second scenario has the potential to engage a number of the spatial-thinking areas of the brain and thus promote more durable learning. This is not an either-or question, however – it is certainly possible to make a rap or other poetic or artistic activity that uses relative positions, sequences along a road or river, wind directions, political hierarchies, and other spatial-thinking ideas as well as just shape and size. The rest of this book is devoted to explaining those concepts about spatial thinking – in this chapter, we simply suggest (with a LOT of research to back us up) that engaging the spatial-thinking parts of the brain will result in better mastery even of the "mundane" task of learning the names of countries.

Additional student activities that involve thinking about locations

A. Play several different variations of the "telephone game"

- Basic telephone game. One person writes a 20- or 30-second story and then tells it to another (use a timer if needed). That second person then tells the story to a third, and so on for half a dozen rounds. Then the last person tells the story back to the first one, who compares the oral story with the written record, and together they describe the differences.
- Location variant. One person thinks of a landscape feature (park, store, restaurant, fishing spot, whatever is locally appropriate). That person describes the location of the feature to another, who tries to think of a different "locational vocabulary" (e.g. adjacency to a feature, position between two other features, distance and direction from a landmark, map coordinates, etc. – see handout on CD). That person uses those different terms to describe the location to a third, and so on for half a dozen rounds. Then back to the first person, as above.
- Map variant. The first person receives a map and a piece of paper describing the location of a feature on it. That person describes the location of the feature to another, using a different "locational vocabulary." That person chooses another different way to describe the location to a third, and so on for half a dozen rounds, and then back to the first person.
- Giving directions variant. The first person receives a map and a piece of paper describing two things: "you are here" and the location of a destination. That person chooses a "locational vocabulary" and uses those terms to give directions from "here" to the destination. That person chooses another different way to give directions to a third person, and so on for half a dozen rounds. Then back to the first person to check for differences.
- Crossing variant. Choose any of the above, but start two messages from opposite ends of the line, so that they have to cross.

For any of these variants, the setup and debriefing are key. Set it up as practice for getting and giving directions prior to a field trip, for example. And use the debriefing time to emphasize the elements that go into good descriptions of location and direction. This folder has some handouts to help clarify the distinctions.

The goal is to produce a generation of people who do not complain "I have a terrible sense of direction." The research is fairly clear – different people do indeed have different aptitudes and inclinations to organize spatial information and give directions in different ways, BUT *everyone can learn how to do it better*. It takes practice, and simply thinking about the fact that the terms and sentences that make the most sense to you might not be the best way to describe a location to someone else. Here's the bottom line: a sense of position and direction is learned, not innate.

B. Different languages of location.

Give students blank maps of the local area, the area of a future field trip, or a part of the world they are about to study. Provide lists of places to know. Have students in groups split up the lists and look up the locations of their fair share in an atlas or online mapping site (or, sometimes, skip this step and simply label the places on the map). Then announce a locational vocabulary (coordinates, for example) and have each student in a group pick one of the places they researched and explain its location to the others in that vocabulary. Then announce that the rules have changed, and they have to do the next round using distance and direction terms from some of the places they have already located. The third round could use topological terms (between, beyond, within, etc.), and so forth. At the end, ask students to think about which language they found most useful, and discuss ways to ask for information in their preferred way.

Detailed review of research on thinking about location

Before we start this section, we should perhaps repeat something from the Introduction chapter, namely that our goal in these detailed-research sections is to try to dig a little deeper into the available research that pertains to each specific mode of spatial thinking. A lot of this research is rather technical, but we think it is useful to see at least some of the research "in the words of the researchers." When the jargon gets too complex, we will try to come up with a simply phrased take-home message for teachers after each handful of paragraphs. Even so, the average classroom teacher may decide that our quick summaries at the beginnings of these essays are enough, at least at first, to provide the necessary background for looking at the sample activities and then devising their own classroom strategies. On the other hand, a number of teachers have told us that they occasionally need some of this "heavy artillery" to help make their points in discussions with parents, curriculum supervisors, administrators, school boards, and other stakeholders in the educational enterprise.

With that as background, here we go. The first thing we should do is admit that the research about "the psychology of location" seems much less clear than one might infer from the simple summary table on the first page of this essay. In fact, for nearly every item on that list, it is possible to find a credible research study that names a different part of the brain as involved in that kind of thinking. Take the first item, the mental or verbal association of a location with a specific landmark feature, as in "the coffee shop is near the Post Office on Jefferson Street." Here is a summary quote from the research study cited in our table:

> "It is likely that the parahippocampal cortex contributes to the establishment of a cognitive map of the environment by providing spatial scene information to the hippocampus. The parahippocampal cortex itself receives visuospatial information from the parietal cortex (A.D. Milner & Goodale, 1995; Ungerleider & Haxby, 1994; Van Hoesen, 1982). It also receives information about specific objects in the environment from the ventral occipitotemporal cortex Areas V4, TE, and TEO (Aguirre, Zarahn, & D'Esposito, 1998; Suzuki, 1996)" (Bohbot et al 2004 p 422).

This kind of prose is not exactly easy to read, but it <u>is</u> possible to pick out the names of specific brain regions. Unfortunately, another article from the same year uses the notion of association in a slightly different way, mentions different areas of the brain, and at the same time admits its uncertainty:

> "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. Despite an increase in research on associative memory, work has lacked a theoretical framework to guide design and interpretation of studies" (Mayes et al. 2004 p 127).

To complicate matters even further, two more studies that were published about the same time add the dorsolateral prefrontal cortex and the anterior prefrontal cortex to the list of brain areas engaged in associative recall (Achim and Lepage 2005; Ranganath et al. 2004).

Obviously, we cannot, as geographers, reasonably expect to enter this kind of discussion about brain activity and sort out all of the possible sources of confusion and disagreement. We can, however, note the major areas of contention and their implications for the design of geographical materials. In that spirit, we will end this chapter by summarizing what some developmental psychologists and brain researchers have said about three related issues – the relative importance of general spatial geometry versus local landmarks in thinking about location, the interplay of global structure and local details in visual perception of location on maps and other images, and the implications of raster versus vector storage of locational information in a GIS.

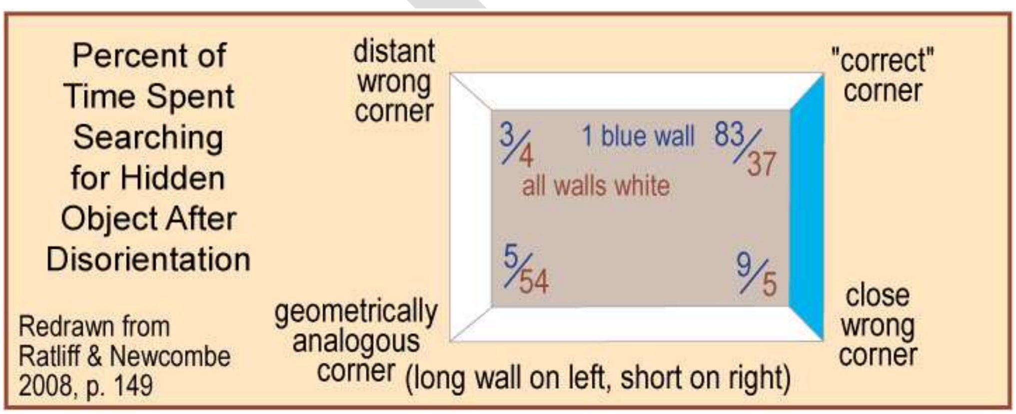
Research issue 1: geometry versus landmarks in personal orientation

To fix their location in space, do people use 1) the overall shape of a room, park, or other environment, or 2) individual landmarks? Specifically, does the human brain have a "geometric module" – a place that processes relative location without conscious thought or regular input from the visual system or other areas of the brain? By the 1990s, studies with a number of laboratory animals had rather conclusively proved that they use the overall shape of a finite area to orient themselves. In 1996, some research seemed to suggest that young children had a similarly "innate" ability:

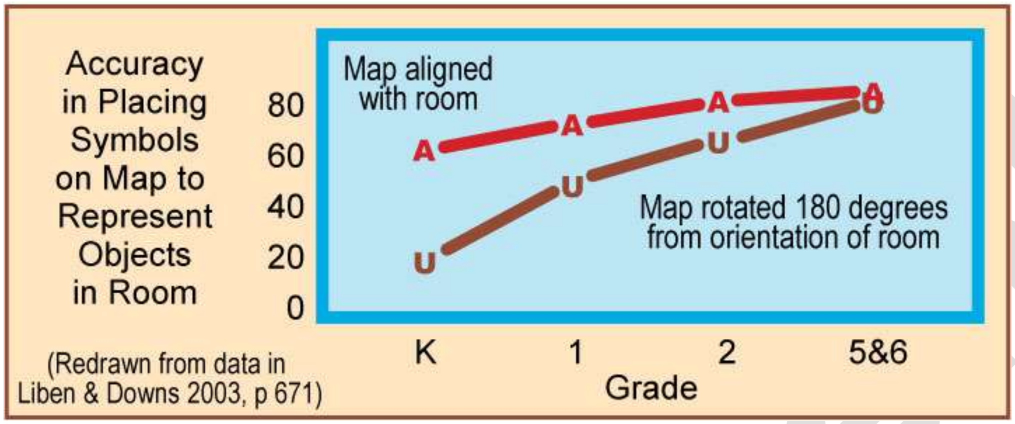
> "In a series of experiments, young [18-24 months] children who were disoriented in a novel environment reoriented themselves in accord with the large-scale shape of the environment but not in accord with nongeometric properties of the environment such as the color of a wall, the patterning on a box, or the categorical identity of an object. . . this failure suggests that children's reorientation, at least in relatively novel environments, depends on a mechanism that is informationally encapsulated and task-specific: two hallmarks of modular cognitive processes" (Hermer and Spelke 1996, p 195).

Later, the same authors added evidence that language was necessary to "override" that innate tendency to orient on the basis of overall geometry of a space (Hermer-Vasquez et al. 1999; 2001). Since that time, dozens of other researchers have examined aspects of this issue. Some looked at the possible effect of changing the size of the room (Learmonth et al. 2002). Some explored the effect of room geometry – rectangular or trapezoidal (Hupbach and Nadel 2005; Sturz et al 2012). Some noted that the choice of orientation strategies might depend at least partly on which eye received the initial impression of the room (and therefore which half of the brain started to process the information first; see Vallortigara and Pagui 2004; see also Kelly et al. 2013). Some even explored the effect of sounds or smells in assisting orientation (Cheng 2005).

By 2007, the weight of opinion seemed to favor a more flexible, less modular approach to reorientation (Twyman et al. 2007; see also Cheng and Newcombe 2005; Bodily et al. 2011). A still more recent study explored the possible effects of internal blocking or interference between brain regions as a mechanism to explain some of the early contradictory findings (Wilson and Alexander 2008; for an additional study of the effects of language as a "mediator" in this process of perceiving a landmark (in this case a blue wall) as well as general geometry (a rectangular room), see Ratliff and Newcombe 2008, the source of this diagram).



All of this is potentially important at a personal scale, for example if we are trying to help someone reorient themselves in a mall that has a badly designed “you-are-here” map. Perhaps the best advice for children is the simplest: you can avoid a lot of orientation problems by turning the map so that it lines up with the external space! Aligning the map with the surrounding world makes it easier to use both landmarks and the overall shape of the space as clues in choosing a route to your destination (Vosmik and Presson 2004; but note that recent work raises the issue of individual differences).



The same advice may have applications at geographical scales. For example, many adults find it easier to use a highway map if they can turn the map to align with the road, other visible landmarks, and the overall geometry of the space around them. This is what most GPS devices do (a convention that they adopted after years of research with focus groups that were convened to provide advice about what approaches were easiest to follow).

That strategy of reorienting a map, unfortunately, is not so easy to use when a badly designed textbook or website map uses an inappropriate orientation to show some part of the world that does not have landmarks that are familiar to map readers. Possible topics of this kind include mineral claims in the Arctic Ocean, transport passes through the Andes Mountains, or whale migrations in the South Pacific. A good map designer can anticipate that problem and solve it by choosing an appropriate map projection and especially by establishing the map extent with some care. A map reader, however, must have enough prior knowledge about the area to cope with maps that have not been designed with adequate care.

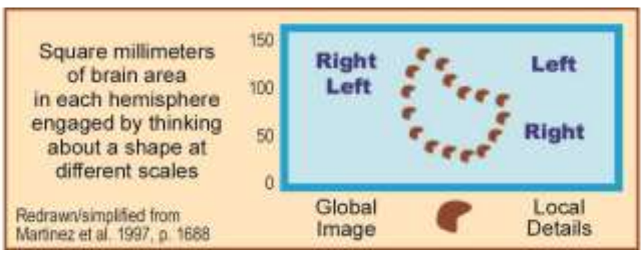
Research issue 2: global versus local in visual image processing

A related question deals with visual perception and how people remember locations on a map, photo, or other visual image. Specifically, do human brains encode the overall appearance of an entire shape first, and then fit the details into that frame, or do they fix the relative locations of some particularly memorable details first, and then build a larger image by connecting those details? We’ve asked this question, in an indirect way, at a dozen teacher’s conferences in recent years – and we have been surprised by how many people have said that their first memories of maps involve highly memorable details, such as the “boot” of Italy kicking the “football” of Sicily, or the “arm” of Cape Cod curling around the landing site at Plymouth Rock.

This particular puzzle was one of the first questions where brain-scanning technologies could help find an answer. In the late 1970s, people were saying that visual attention usually began with a broad overview and then zoomed in to focus on specific details (Navon 1977). By the early 1990s, behavioral psychologists had concluded that the process was not necessarily fixed, because people could be “cued” to focus on either global structure or local details in a complex scene (Robertson et al

1993; Awh et al. 2000). Others reported that the relative importance of local or global focus seemed to change with age, making a gradual shift from primarily local to global attention as a person gets older (Akshoomoff and Stiles 1995). Still others noted that people seemed to "automatically" encode the locations of things like photographs on pages (Ellis 1990 – good news for map designers!)

Then brain-scanning technologies became widely available, and the research floodgates opened. One group used some early scanning technology and reported that the choice of global or local focus seemed to involve different areas of the brain: "In a directed attention task, early visual processing (prestriate) areas were activated: attention to the global aspects of the figures activated the right lingual gyrus whereas locally directed attention activated the left inferior occipital cortex" (Fink et al. 1996, p 626). In the next year, researchers used a more precise scanning method to home in on two small areas of the brain that appeared to be involved in global and local visual processing (Martinez et al. 1997; compare the detailed lesion study in Amorapanth et al. 2010).



Another year later, a study used a somewhat different brain-scanning technology and concluded that

> "early sensory inputs are not modulated to gate global versus local information differentially into the two hemispheres. Rather, later stages of processing that may be asymmetrically organized in the left and right hemispheres operate in parallel to process global and local aspects of complex stimuli (i.e., the N2 effect of the ERPs). This pattern of results supports models proposing that spatial frequency analysis is only asymmetric at higher stages of perceptual processing and not at the earliest stages of visual cortical analysis" (Heinze et al. 1998 p 485).

With the basic idea of brain asymmetry now fairly firmly established, researchers began to focus on the effects of age, sex, handedness, and other variables. This really multiplied the number of research studies. For example, one group reported that "with age, children's development was marked by a left hemisphere advantage for local level processing that resembled an adult's and a trend toward right hemisphere advantage for global" (Moses et al. 2002, p. 415). One year later, however, a study concluded that the "adult" tendency to favor global-scale visual processing can be reduced or even reversed by manipulating variables such as duration, visual angle, or stimulus density (Navon 2003). Other studies stretched the idea of location to include things like shape recognition and dot pattern analysis, which we will consider in greater detail in the essay on spatial patterns (noteworthy examples include Burack et al. 2000, Dukette and Stiles 2001; Aspell et al. 2006; Nucci et al. 2007). A more recent study reinforced the idea of a transition from local to global preference in childhood, but noted that the meaningfulness of the stimulus had a great effect on the timing and thoroughness of the shift (Poirel et al. 2008). This conclusion has implications for the design and use of educational materials, especially when combined with the results of a slightly earlier study that emphasized the importance of hearing relational language as a "instrumental in the development of abstract thought" (Loewenstein and Gentner 2005, p348).

Meanwhile, in a completely different part of the knowledge world, a number of robot engineers have been trying to assess the relative importance of global structure and local landmarks in helping a mobile robot keep track of its location and choose a route to a destination. As noted in Chapter 6, summaries of this research can be difficult to find, because much of it is reported in meetings and conference proceedings. Some of those conferences and reports are widely accessible, but many are by-invitation-only, perhaps because the results can have great commercial value and/or military importance! In general, however, this more-or-less independent research has converged on some of the same questions and answers (for accessible but undoubtedly out-of-date summaries of this research, see Thrun 1998; Kuipers 2000; Steck and Mallot 2000; Bailey and Nebot 2001; Tomatis et al. 2003; Vasudevan et al. 2007; Zender et al. 2008; to help decode the results, it might help to be aware that many robot engineers use the words *topological* and *metric* as rough synonyms for what psychologists call *global* and *local*).

Note: As a mnemonic aid to help remember the core message from all of these studies, you might simply compare the titles of the first and last study we cited, as well as one key article that was published about the same time as researchers began using brain-scanning technologies:

> "Forest before trees: The precedence of global features in visual perception" (Navon 1977)
>
> "Where in the brain does visual attention select the forest and the trees?" (Fink et al. 1996)
>
> "First came the trees, then the forest: Developmental changes during childhood in the processing of visual local-global patterns" (Poirel et al. 2008)

If you think this change in opinion might possibly influence the design of maps and other visual aids for classroom use, you might be interested in the title of an article written just as the brain-scanning era began: "The process of learning from small-scale maps" (Rossano and Hodgson 1994). The authors of that article concluded that:

> "there was a global to local learning process . . . based on the spatial structure inherent in the map . . . the subject begins with the most global spatial category [and] then proceeds to differentiate further down the spatial hierarchy . . . eventually, the subject works his/her way down to the most local spatial level on the map" (Rossano and Hodgson 1994, p 565, 581).

This sounds plausible, but the majority of brain-scanning research done since that time seems to suggest that the process actually works in the opposite direction for many children and some adults.

What does this all mean for teachers? For one thing, we probably need to rethink some ideas about map design for educational purposes. This essay is not the place for us to pretend that we have an easy one-page answer to a question that has intrigued us for decades. We will therefore duck this question, for now, and conclude this section with one recommendation, followed by a short story from each of us, and a final conclusion.

The recommendation is that teachers try to focus student attention on the inevitable tradeoffs of scale, size of area, and detail at least once every few months. Have students note what kinds of details often get omitted as map-makers simplify their maps in order to show a larger area on a single page or computer screen. One good way to do this is by using one of the popular highway-mapping or satellite-image programs, such as Google Earth or Yahoo Maps. The goal is to try different ways to diagnose whether students are having difficulty in making connections between local detail and global overview or vice versa.

That brings to our stories. Phil's is shorter and much less scientific than Carol's. He distinctly recalls a midnight flight to Hawai'i, his first trip off the continent of North America. The weather conditions were normal, which meant that the prevailing wind over the islands was from the northeast. The pilot therefore aimed the plane in a big circle and approached the Honolulu airport from the west. It was midnight, for the fourth time as we crossed time zones, and Phil was sound asleep during the turn. He woke up as the wing flaps came down with an audible thud, and he looked out of the window on the left side of the plane and saw the lights of "Honolulu" (actually, Ewa Beach). Since, in his mind, he had flown westward from Los Angeles, and the lights were on the left, obviously Honolulu must be on the north side of the island as he approached it from the east. It took about four months, plenty of maps, and numerous observations of sun angles and shadows, before he finally overcame that initial frame-of-reference misperception and could mentally put the city in its proper location on the south side of the island. The moral of that anecdote? misconceptions about relative location can be surprisingly durable!

Carol's story is about a research study that she did with about 240 4th grade students in the late 1980s. Her study involved maps with several different degrees of complexity. Some showed only roads, some showed political areas, and some showed both kinds of information. Those three kinds of background were then used on maps where the main purpose was to show the locations of a handful of point features - the school, sports stadium, science museum, and so forth.

The first question in this study was simple – would children remember the locations of the point features better if they saw them on simple maps or on more complex maps? (Other questions dealt with distance from the schools to the points of interest and the order in which children saw the maps, complications we will not discuss here). Some results of the study were presented at a professional conference in 1991, three years before the map-reading paper cited above was published (Gersmehl 1991). Basically, Carol's study came to a different conclusion - she found clear evidence that students who were led to focus on the details of complex maps were able to recall the locations of points more accurately than students who saw just the simple political or highway information.

Her study had one characteristic that set it apart from many other research studies being done at the time. Her study used actual (non-hypothetical) maps that showed the locations of specific places that students might have visited or heard about – places like the Mall of America, Science Museum, and Vikings stadium. By contrast, the map-learning study cited above used a sketch map of an imaginary island called Caspia (Rossano and Hodgson 1994). The majority of studies in other psychology journals also use imaginary maps, some consisting of nothing more than a map-like array of printed names of unrelated objects, such as coins, linen, radio, and soap (we dislike singling out a few individuals here, because so many others also use equally unrealistic imaginary maps, but these particular examples came from Kealy and Webb 1995 and McNamara and Diwadkar 1997).

One plausible conclusion is that if we want to do research on how children learn locations of features from maps, we probably have to use maps with features from the real world, arranged as they are in the real world! As Leonard Guelke said, "the crucial feature of a map is not the information in contains per se, but whether that information is set in an appropriate context. . . . the meaning of a specific location is largely defined in terms of the location of related elements" (Guelke 1976, p. 135). The key is to think carefully about what elements within an area are truly "related" to the location; those are the details that people should see on the map. In short, we should design maps carefully, because a number of studies have shown that the brain can process a relatively large number of visual objects, but "implicit" (unconscious) identification of irrelevant objects can interfere greatly with the gathering of spatial information from a map (Poirel et al. 2006).

This is one reason why we have serious reservations about artistically designed children's atlases that feature colorful images scattered around the map. There is no question that these atlases are attractive at first glance – but, as with a Coke vs Pepsi taste test, initial impressions should not be the only criteria that we use in designing educational materials. In this particular case, we think that a careful search of available research underscores the need for well-controlled studies that look at what kinds of maps actually promote durable learning of locations and geographical relationships. Carol's story shows how time-consuming a controlled study of that kind can be; Phil's story adds that a single erroneous first impression about location can bias understanding for a surprisingly long time!

Research issue 3: raster versus vector encoding of location in a GIS

We have just spent several pages looking at two issues where psychologists, brain scanners, vision scientists, linguists, and robot engineers have done thousands of research studies. The issue of raster versus vector encoding of data has generated a similarly large volume of research, but most of it dealt with technical issues like storage efficiency, processing time, and error propagation. Readers who know us are aware that, in street talk, we have "been there, done that" (we have been active participants in that kind of GIS "debate" for decades – see, for example, Gersmehl 1987). For now, we will thankfully declare most of that research outside of the scope of these essays, <u>except</u> for one important observation:

> Amid all of the technical research about GIS file structures and display technologies, there is an emerging need for some psychological research about how people actually perceive and mentally encode locations and other information that they see on a GIS display.

Specifically, there may be questions about whether people truly understand the fundamental difference between raster and vector data – a difference that admittedly does not matter for many maps, <u>unless</u> both kinds of data are part of an overlay or other data-combination process that results in a composite map. At that point, it is worthwhile to have a clear understanding of the difference.

Here, for readers who may not have encountered the terms, is a quick summary:

> A **raster** image is like an enormous piece of graph paper laid over an area. Each square on the graph is labeled according to some characteristic observed at that place - its surface cover, for example, or soil type, crop yield, land value, noise level, etc. The rods and cones in your eyeball form a kind of raster map of what you "see." So does a digital camera, a sensor on an orbiting satellite, or a .jpg, .pic, or .tif file in your computer. Each nerve impulse from your eye or message from a satellite sensor is a generalization about the average radiation emitted or reflected by a specific area "out there." The individual grid cells of a satellite image might be the size of a football (some military satellites), a small car (some new civilian satellites), a suburban house (the workhorse Landsat system), or a large forest (some weather satellites). The appearance of a raster image is related to the size of the individual grid cells – tiny cells can provide a detailed image, whereas large cells provide a coarse, blocky image.
>
> The problem is that to make an accurate fine-grained raster image you actually have to observe the conditions in each cell, and there can be billions or even trillions of cells. That kind of observation is difficult for many topics, such as noise level, crop yield, or per-capita income. The alternative is to make some assumptions about how things are in the world, and then use those assumptions to interpolate between the cells where you actually have measurements or direct observations. The technical questions for GIS specialists deal with the tradeoffs between accuracy and the costs of data gathering, storage, and manipulation for different sizes of raster cells. The psychological question for teachers is whether viewers really understand what they see when they look at a map that was made by a computer that has been programmed to:
>
> - electronically interpolate between observations,
> - rescale the resulting raster file, and then
> - combine it with some other kind of data in a composite image

An example might be a map of fire damage, which is made from a raster satellite image plus a vector map that shows a handful of measurements made on the ground (read on!).

A **vector** map consists of points, lines, and areas that have been translated into mathematical coordinates. Usually, those coordinates are tied to a conventional frame of reference, such as latitude-longitude or UTM.

- A point feature, such as a survey marker, is encoded as a single set of x,y coordinates.
- A line feature, such as a road or powerline, is encoded as a series of coordinates. Mapmakers can reduce file size by deriving an equation that is an acceptable mathematical generalization of the line.
- An area feature, such as a country or forest, is encoded as a line that goes in a conventional direction (e.g., clockwise) around the area. In other words, to make a vector area map, someone has to draw a line around an area, specify the coordinates of the line, and enter those numbers into the computer, with some kind of hint about what side of the line is "inside."

The technical questions for mapmakers usually revolve around the method of interpolation between measurement sites (for point measurements) or the choice of a *minimum size of delineation* (for area observations). Here are some specific questions: how small an area do we identify and encode as a separate entity, and how many dissimilar "inliers" within an area are we willing to accept on a map? The psychological questions for teachers deal with the human tendency to perceive a delineated area on a map as uniform, when in fact it may have dissimilar inliers and local variations that have been masked when someone just drew a line around the area and declared it a single object.

Now, let's look at how these differences affect the human perception of the idea of location. If information originally came from a satellite image, digital camera, or other raster source, its location cannot be expressed any more accurately than about half the width of the raster cell. The coordinates in a vector map, by contrast, can be exceptionally precise, but the actual location of a point, a line, or the boundary around an area depends on the skill of the map maker and the precision of recording the location of the observations that support the map. On a computer display, however, a vector map gives a psychological impression of great precision, whereas a much finer-grained raster map still gives an impression of blockiness.

The core message is that most of the technical questions about data encoding have been quite thoroughly explored, and we have fairly accurate estimates of various kinds of encoding and data-manipulation "errors." It would be useful, however, to have a much better collection of research-based answers for the psychological questions about how humans perceive locations on different kinds of maps. As computer-assisted mapping from very large data files becomes more prevalent in society, those questions are likely to become more important.

We end this chapter where we began – with the statement that the human brain does not have any structure for encoding and remembering absolute location. People calculate location in a number of relative ways as they do everyday things, such as walking through buildings, looking at satellite images, or studying maps. To encode or express location, people use a number of cognitive processes that are part of we call spatial thinking. To communicate these ideas to others, they encode the spatial relationships into language (which points at yet another fruitful field for research – for different perspectives on an enormous body of research, see, for example, Kemmerer 2005; Noordzij et al. 2008; Li and Zhang 2009; Haun et al. 2011; Plumert et al. 2012).

The specific modes of spatial thinking that people are likely to use for a given topic at a specific scale are still a subject of research. In this project, we will review many of those research studies in the essays that deal with each particular mode of spatial thinking.

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