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Levels and Structure of Spatial Knowledge

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INTRODUCTION

In order to get from here to there without the benefit of external cognitive aids, like maps or written instructions, a traveller needs knowledge of different kinds. At a global level, the traveller needs a mental representation of an area that includes 'here' and 'there' and regions around and between them. Let's call that 'overview' knowledge. Using that, the traveller determines a feasible route. Along the route, and especially at choice points, the traveller needs a representation of the local surroundings, with the information critical to the choice highlighted. Let's call that knowledge 'views.' At yet a finer level, the traveller needs to know how to take each step or each turn of the wheel, maintaining course while avoiding pitfalls and obstacles. We'll refer to that as 'actions.' Each of these levels, and they are by no means all, calls up different sorts of information from the world and the mind and joins them in ways judged appropriate to the task at hand (see Freundschuh and Egenhofer, in press; Mark, 1992; Montello, 1993; Tversky *et al*., in press; for analyses and reviews of mental geographic spaces). Those engaged in making a robot into a competent traveller have discerned these levels of information, and more (e.g., Chown *et al*., 1995; Gopal *et al*., 1989; Kuipers and Levitt, 1988).

On the one hand, wayfinding is an everyday task, essential to survival, that has been accomplished by people since they evolved and by other organisms before that, using their eyes and bodies and minds. In people, language adds yet another layer of information about space. On the other hand, this apparently simple activity has presented serious challenges to the design of robots, and those challenges have elucidated the many aspects of knowledge and skill that must be combined to successfully get from here to there. Thus, psychologists, geographers, anthropologists, neuroscientists, linguists, and computer scientists are among those who have been captivated by the study of spatial knowledge (see Mark *et al*., in press; Tversky, in press; for historical reviews).

Of course wayfinding is not the only use to which spatial knowledge is put. We use spatial knowledge to understand history and politics, to decide where to live and visit, and to make sense of the natural world around us, such as weather, stars, rocks, rivers, plants, and animals, anything that is distributed spatially in the world. Thus, the information about the spatial world that we encode and remember should be general and varied enough to serve purposes both known and not yet known. Spatial knowledge is diverse, complex, and multi-modal, as are the situations in which it is used.

In what follows, I will first discuss evidence characterising mental representations at each of the three levels, overview, view, and action. Then I will consider the special case of language, especially with respect to overview descriptions and route directions.

OVERVIEW LEVEL: COGNITIVE MAPS

The endearing yet controversial notion 'cognitive map' was coined by Tolman (1948) to declare that through experience traversing mazes in search of food, even hungry rats learned the general configuration of the mazes over and above specific routes to rewards. How to characterise a cognitive map has been the source of debate (e.g., Kuipers, 1982; Tversky, 1993). All seem to agree that a cognitive map is a mental representation of an external environment. At one extreme are those who appear to believe that a cognitive map is like a map on paper (or a mental image, Kosslyn, 1980); that is, a more or less veridical, more or less metric, unified representation of the environment. At the other extreme are those who appear to believe that a cognitive map may be an ad hoc collection of information from different sources put together to solve a particular problem; as such it has no inherent unity and no guarantee of consistency or veridicality. The mind contains many different kinds of knowledge structures, some truer to perception, more metric, more consistent, for example, images (Kosslyn, 1980). Others may bear structural similarities to some state or process in the world, yet are categorical and more abstract, such as mental models (e.g., Gentner and Stevens, 1983; Johnson-Laird, 1983; Tversky, 1991). Still others may be closer to an hodge-podge of multi-modal information, called a 'cognitive collage' (Tversky, 1993). There is no reason to doubt that for some people and for some environments, mental representations are more like maps on paper and for other situations, more like collages. Nevertheless, considerable evidence from various cognitive tasks that draw on environmental knowledge suggests systematic biases and distortions that do not seem to be reconcilable in a consistent map-like structure (e.g., Tversky, 1981; 1992).

All conceptions of cognitive maps recognise that, as for maps on paper, not all the information in the environment is represented. Rather that information is schematised. Much information is left out, some information is simplified or idealised. In his influential book, Lynch (1960) put forth the components from which images of cities are constructed: landmarks, nodes, paths, edges, and regions. Even more abstractly, these can be regarded as elements, such as objects, landmarks, streets, cities, countries, intersections, depending on the scale of the representation, organised in a spatial reference frame. In cognition, elements are represented relative to each other and relative to a spatial reference frame. Each of these relations can systematically distort spatial information. Elements, then, correspond to 'what' and spatial relations to 'where' in the dissociable systems in the brain (e.g., Ungerleider and Mishkin, 1982).

Other Elements

Alignment

When elements are located relative to each other, they are remembered as more aligned relative to a reference frame than they actually are. Consistent with this, a majority of people reject a veridical map in favour of a distorted one in which North and South America are placed closer to one above the other, that is in closer north-south alignment, than they actually are (Tversky, 1981). Similarly, a majority of respondents reject a veridical map of the major continents of the world in favour of a map in which North America and Europe appear in greater east-west alignment. That such effects are the result of perceptual organisation, akin to Gestalt proximity, is supported by identical findings for pairs of cities, artificial maps, and meaningless blobs (Tversky, 1981).

Cognitive Reference Points

In any actual environment, certain elements are more prominent than others, perhaps because of perceptual salience, perhaps because of functional significance. These privileged elements, typically called landmarks serve as reference points for many less distinguished elements (e.g., Couclelis *et al*., 1987; Shanon, 1983). They then come to organise the space around them, defining neighbourhoods. Distance estimates from ordinary buildings to landmarks are smaller than distance estimates from landmarks to ordinary buildings, as if landmarks draw ordinary buildings toward themselves (e.g. McNamara and Diwadker, 1997; Sadalla *et al*., 1980). This asymmetry of distance estimates is a violation of metric models of space. Distance asymmetries also appear between prototypic and atypical colours (Rosch, 1975) and prototypic and atypical exemplars of abstract categories (Tversky and Gati, 1978).

Frames of Reference

Frames of reference not only serve to locate and orient entities within them. They also allow integration of different spaces into a common space. There are several natural frames of reference for environments.

Hierarchical Organisation.

One natural reference frame for cities is the states that contain them; at a finer level, a natural reference frame for buildings are the neighbourhoods that contain them. Though flat, spaces are conceived of hierarchically. Using an example immortalised as an item in Trivial Pursuit, Stevens and Coupe (1978) found that the relative directions of cities are distorted toward the overall directions of the states they are in. A majority of students in San Diego incorrectly indicated that San Diego was west of Reno. The distortion was obtained for other pairs of cities, and for artificial maps. Times to make direction judgements are faster when the two elements come from different geographic entities than when the elements to be compared are from the same geographic entity, state or country (e.g., Maki, 1981; Wilton, 1979). Evidence for hierarchical organisation comes from distance judgements as well as direction judgements. In general, distance estimates are smaller between pairs of elements within a geographic entity than between elements located in different geographic entities (Allen and Kirasic, 1985; Hirtle and Jonides, 1985). Comparable errors appear for small spaces devoid of meaning (e.g., Huttenlocher *et al*., 1991; Lansdale, 1998).

Canonical Axes

Another common reference frame for environments are the north-south east-west axes of the world. These distort the directions of the elements within them, as orientation of elements is often conveniently remembered relative to the orientation of an axis of the frame of reference. For example, people 'upright' a map of South America when placing it into a set of north-south east-west axes (Tversky, 1981). In its natural orientation, South America appears tilted relative to the canonical axes. Similar errors have been shown in judgements of directions between pairs of cities in the world, in memory for directions of roads, in memory for artificial maps, and in memory for meaningless blobs (Tversky, 1981) and has been replicated in other situations (Glicksohn, 1994; Lloyd and Heivly, 1987).

Other Distortions and Biases

Perspective

It is well-known in vision that nearby distances are easier to discern and therefore prone to exaggeration than faraway distances. Interestingly, this bias appears in mental spaces as well.

Students were asked to imagine themselves either on the east coast or the west coast. Then they were asked to judge the relative distances between pairs of cities scattered more or less evenly across the US, east to west. Students overestimated the distances of pairs of nearby cities relative to pairs of faraway cities (Holyoak and Mah, 1982). This occurred for both perspectives, suggesting that for mental spaces, perspective choice is flexible.

Distances

As we have seen, distance estimates are judged to be relatively smaller for pairs of places located in different geographic entities than for pairs of places located in different geographic entities. Short distances are overestimated relative to long ones (e.g., Lloyd, 1989), a general finding in estimates of quantity (e.g., Poulton, 1989). Distance estimates are often exaggerated when there are barriers along a route (e.g., Kosslyn *et al.*,1974; Newcombe and Liben, 1982), when there is clutter from increasing objects (Thorndyke, 1981), turns (Sadalla and Magel, 1980), number of nodes (Sadalla and Staplin, 1980b), and amount of information retained from the environment (Sadalla and Staplin, 1980a). Positive affect, on the other hand, seems to shorten distance estimates (Briggs, 1973; Golledge and Zannaras, 1973).

Simplifications

Curves are often remembered as straighter than they actually are, whether rivers, the Seine by residents in Paris (Milgram and Jodelet, 1976) or roads, by experienced taxi cab drivers in Pittsburgh (Chase, 1983). Angles of intersections are schematised to 90 degrees (Moar and Bower, 1983). Regions are remembered as more symmetric than they actually were (Howard and Kerst, 1981; Tversky and Schiano, 1989), and the estimated areas of regions shrink in memory (Kemp, 1988; Kerst and Howard, 1978).

Views

Cognitive maps, however conceived, schematise the two-dimensional horizontal slice of the world. By contrast, views schematise vertical slices of the world. They have also been called 'You Are Here' pointers, consisting of a place description, a path description, a direction, an orientation, and a heading (Kuipers, 1978). People's memory for horizontal views of places had been thought to be excellent (Shepard, 1967; Standing, 1973); however, recent research indicates that although general recognition of environments is excellent, changes in details and objects often go unnoticed, provided the general configuration remains the same (Simons, 1996). Scenes that are organised are remembered better than scenes that are unorganised, where the organisation is primarily vertical, governed by gravity (Mandler *et al*., 1977). Scenes fall into natural categories. At the highest level, indoor scenes are distinguished from outdoor scenes. At the basic level, people categorise outdoor scenes into beach scenes or city scenes or forest scenes and categorise indoor scenes into schools, restaurants or grocery stores (Tversky and Hemenway, 1983). Scenes seem to be so important to human behaviour that a region of the parahippocampal cortex appears to be dedicated to recognition of them (Brewer *et al*., 1998; Epstein and Kanwisher, 1998). From the point of view of wayfinding or geographic information, the most important features of views are landmarks.

Space at the view level can also be experienced in three dimensions with the help of memory, as the set of objects surrounding the body. People are able to keep track of the relative positions of the objects around themselves effortlessly, even when the objects are not visible. People seem to do this by constructing a spatial mental framework from extensions of the three body axes and associating objects to the axes. The relative accessibility of objects depends on their directions from the body. Enduring properties of the body and the perceptual world appear to determine the relative accessibility of the axes. When upright, the head/foot axis is most accessible because it is an asymmetric axis of the body and aligned with gravity. The front/back axis is next, as it is also asymmetric, whereas the left/right axis is slowest because it has neither salient asymmetries nor any association with an environment axis (Franklin and Tversky, 1990). A variant of this analysis accounts for memory retrieval times for objects in three-dimensional displays in front of observer, with the same ordering of axis accessibility (Bryant *et al*., 1992).

Action Level

Somatosensory and vestibular information. Although information about elements and spatial relations is important at overview, view, and action levels alike, somatosensory and vestibular information is especially important for the action level. Rieser (1989) has compared spatial relation judgements after real and imagined movements. In his task, participants learn a room-sized environment from observation at a particular viewpoint. Then they are blindfolded. One group is led to a new station point and the other group is asked to imagine themselves at a new station point. From the new real or imagined location, both groups are asked to point to other objects in the room. For translated movements, the navigation and imagine groups were equally fast and accurate. However, for rotational movements, the actual navigation group performed faster and more accurately than the imagine group (see also Easton and Sholl, 1995; Presson and Montello, 1994). Actual movement seems critical for keeping track of orientation. This may be because in some imagined rotations, participants fail to keep track of their changed headings (Klatzky *et al*., 1998; but see also Franklin and Tversky, 1990, where in a different paradigm, imaginary rotations are accurate). For translations, there is no change of heading. Other research has shown that in blindfolded participants, somatosensory and vestibular information is important for keeping track of turning motion (Berthoz *et al*., 1995; Takei *et al*., 1996). This sensory information may be used to infer headings and spatial relations of surrounding objects. That somatosensory and vestibular information is integrated into a schema of the environment is suggested by experiments showing that counting backwards out loud interferes with keeping track of motion (Takei *et al*., 1997).

Learning from Exploration vs. Maps

Consistent with the conclusion that the sensory information provided by actual exploration contributes to the formation of mental representations of environments, and especially to orientation, Thorndyke and Hayes-Roth (1982) found that people who learned a two-building complex through actual exploration were more accurate pointing to the directions of landmarks in the complex than those who learned the complex from studying a map.

Explorers were not superior on all judgements; in fact, those who learned from maps were more accurate in estimating direct distances between pairs of points.

Space of the Body

Action involves the body. Somatosensory information also seems to contribute to knowledge of another space important in navigation, the space of the body. Unlike other objects, people experience bodies from the inside as well as the outside. Because sensorimotor information is not equally distributed over the body, this view predicts that some parts of the body should be more salient than others. In accordance with this, Reed and Farah (1995) found that moving the upper body facilitated detection of upper body differences in pictures of body postures and moving the lower body facilitated detection of lower body differences in pictures of body postures. Moreover, upper body changes were detected better than lower body changes, consistent with the greater sensorimotor innervation of the upper body. Further evidence for and development of this position was provided by Morrison and Tversky (1997). In a task requiring verification of named body parts with body parts highlighted on pictures of bodies, participants were faster to verify more significant than to verify large parts, where significance was loosely indicated by relative sensorimotor innervation.

FUTURE

Since its disparate beginnings, the seminal work of the rat psychologist Tolman and the urban architect Lynch, to name but a few, the field of cognitive maps has made fascinating progress. The progress has been the result of efforts by psychologists, geographers, computer scientists, linguists, anthropologists, and others. I've reviewed only a small fraction of the work here; the other chapters provide more. Despite the progress, many fascinating problems remain unsolved, including some of the very basic issues. How do we get from actions and views to overview knowledge of the world, from our own situation-based experiences to knowledge more abstract that allows us to behave intelligently in new situations? How do we integrate different kinds of information from different barely comparable sources? How do we retrieve the right--or wrong--particular information that we retrieve in any particular task?

Language of Space

Important as experience may be, in people, language serves as an impressive surrogate for experience. Well-told stories can bring tears to our eyes, whether from happy or funny or sad descriptions. The way something is described, either by ourselves or by others, affects our interpretation of it and our memory for it (e.g., Carmichael *et al*., 1932; Levinson, 1996; Loftus and Palmer, 1974; Schooler and Engstler-Schooler, 1991; Tversky and Marsh, 1998). Language has additional advantages. It is lightweight and portable. It allows mental transport to other times and places, freeing us from our own place and time and body. The evocative properties of language are especially important for describing space. Duras evokes the sultry scene in colonial Vietnam as Hardy evokes the rolling, windswept moors of England. Spontaneous descriptions can successfully guide travellers to their destinations, even in such arcane environments as Venice (Denis *et al*., 1998; see also Streeter *et al*., 1985). Language is by nature categorical, though it does have devices for conveying continuous information. In any case, language is more reliable for conveying categorical spatial relations than exact ones (e.g., Leibowitz *et al*., 1993).

We are all experts in describing space just as we are all experts in navigating space. Spatial descriptions do a number of things. Of particular concern here, they locate landmarks, typically relative to each other and to a reference frame. When complete and coherent, spatial descriptions all by themselves have the power to provide an adequate representation of an environment, a spatial mental model, either an overview (e.g., Taylor and Tversky, 1992a) or a view (e.g., Franklin and Tversky, 1990). Route directions are a special kind of spatial description, designed to take a traveler from one point to another rather than to give an overall impression of an environment. Spatial language has been studied primarily at the levels of overview and view, though there is recent work on describing actions (e.g., Habel and Tappe, in press; Tappe and Habel, 1998; Zacks and Tversky, 1999). For the most part, such descriptions are of intentions rather than motor activities.

Styles

When (English or Dutch speaking) people are asked to describe environments, they adopt one of three styles (Taylor and Tversky, 1996). For small environments that can be seen from a single point of view, usually an entrance, people use a gaze tour. They take a single viewpoint in the environment, usually an entrance, and describe the landmarks, typically objects in a room, relative to one another in terms of left, right, front, and back relative to the natural viewpoint (Ehrich and Koster, 1983; Ullmer-Ehrich, 1982). When describing larger environments that cannot be seen from a single viewpoint, people use either a survey or a route perspective or a mixture of both (Denis, 1996; Linde and Labov, 1975; Levelt, 1982a, 1982b; Taylor and Tversky, 1992a, 1996; Tversky, 1996; Tversky *et al*., 1997). In a survey description, people take a viewpoint from above and describe landmarks relative to each other in terms of an extrinsic reference system, normally the canonical north-south east-west axes. In a route description, people take the changing viewpoint of a traveler, typically characterised as 'you', in an environment, and describe locations of landmarks relative to your current position in terms of your left, right, front, and back (Taylor and Tversky, 1992a, 1992b, 1996).

Surprisingly, people frequently mix these styles in describing an environment, often without signalling and without noticeable costs in comprehension (Taylor and Tversky, 1992a, 1996). This is in spite of the fact that perspective switches can require extra time to process during reading (Lee and Tversky, in preparation). The configuration of an environment is at least in part responsible for the choice of description style. For example, survey descriptions are relatively more popular in English for environments that contain multiple routes or that contain landmarks at multiple scales (Taylor and Tversky, 1996).

Reference Frames

These three perspectives correspond to the three frames of reference distinguished by Levinson (1996). Previous analyses of perspective in language had distinguished three perspectives based on the referent, the speaker or viewer, an object, or an environment, and the terms of reference (see, for example, Buhler, 1934; Fillmore, 1975, 1982; Levelt, 1984; Miller and Johnson-Laird, 1976). These analyses led to conceptual difficulties, especially in distinguishing a 'deictic' perspective based on a speaker or viewer from an 'intrinsic' one based on an object. There didn't seem to be any principled difference between describing the location of a ball as 'in front of me' or as 'in front of the house' as long as it was clear that 'front' referred to the inherent side of the person or object.

To correct the ambiguities of the previous analyses while preserving the alliance of reference frames with reference objects, Levinson (1996) proposed a new analysis of relative, intrinsic, and absolute reference frames. A relative frame of reference is based on a person; it locates a target object relative to a reference object with respect to the person, in terms of the person's front, back, left, and right. To specify such a relation requires three terms, the person, the target object and a reference object. This is one of the cases classically called deictic, as understanding the expression depends on knowing the person's viewpoint. An intrinsic reference frame is based on an object; it locates a target object relative to a reference object with respect to that object's intrinsic front, back, left, and right, a binary relation dependent on the target and reference objects, and not dependent on knowledge of a viewpoint. It does require that the reference object have intrinsic sides, which is not the case for many objects, such as ball. Because they use the same terms of reference, relative and intrinsic reference frames can require disambiguation. If I say 'my bike is left of the house' it's not clear whether I mean to my own left as I look at the house or to the house's left. Finally, an absolute reference frame is based on an environment; it locates a target object with respect to a reference object in terms of, typically, north-south-east-west (other absolute reference frames are possible, for example, seaward and inward). Like an intrinsic reference frame, it does not require knowledge of a viewpoint but unlike an intrinsic reference frame, it does not require that the reference object have intrinsic sides. However, it does depend on knowledge of the cardinal directions.

The three reference frames proposed by Levinson (1996) are idealisations. Mixed cases exist, for example, an inanimate object like an entrance can be used as if it were a viewer in a relative description, and a person can be used as a referent object in an absolute description.

Now we can map Levinson's reference frames onto the three perspectives people take in describing space. The gaze tour adopted for environments that can be viewed from a single point uses a relative frame of reference, whereas a route description uses an intrinsic frame of reference with 'you' as reference object and a survey description uses an absolute frame of reference. These three styles of description correspond to natural ways of experiencing environments, a gaze tour to experiencing from a single viewpoint at eye level, a route description to experiencing from travelling within an environment, and a survey description to experiencing an environment from above (Taylor and Tversky, 1996; Tversky, 1996).

Reference Objects

Using a reference frame imposes a heavy cognitive demand on speakers as well as addressees. To understand and often to produce relative or intrinsic or absolute descriptions requires mentally taking a viewpoint and mentally computing directions from the viewpoint. Some directions are easier than others; in particular, left and right are more difficult in general than front, back, above, and below (e.g., Bryant, Tversky, and Franklin, 1992; Franklin and Tversky, 1990). Some languages do not use left and right in referring to locations of objects, even for tabletop environments indoors, preferring an absolute system of reference (Levinson, 1996). A far simpler, though not always possible, way to describe locations of objects is 'near X' where X is a known landmark. Understanding 'near' does not require taking a perspective or computing directions. It does assume an environment simple enough that direction information is not needed to specify the target object. In simple situations requiring specification of one of two identical objects in spatial arrays with or without landmarks and with or without indication of cardinal directions, speakers indeed used 'near' frequently, ignoring the other information available for specifying the target object. They did so often even when it seemed to violate the principle of taking the other's perspective to reduce cognitive load. That is, they said, 'the one near me' (Tversky, Taylor, and Mainwaring, 1997).

This utterance does not require taking the speaker's perspective; rather, it uses the speaker as a reference object for locating the target. Interestingly, Japanese speakers were as likely to so as American (Mainwaring *et al*., 1999).

Route Directions

Route directions have been a source of fascination as well as a laboratory for linguists, psychologists, geographers, and computer scientists, among others (e.g., Couclelis, 1996; Denis, 1997; Denis *et al*., 1998; Freundschuh *et al*., 1990; Gryl, 1995; Klein, 1983: Tversky and Lee, 1998; Levelt, 1989; Wunderlich and Reinelt, 1982). Route directions are a paradigm case for studying directions, for studying the linearisation of multi-dimensional situations that language requires, for studying spatial language. Those interested in language have distinguished several stages in route directions (e.g., Couclelis, 1996; Denis, 1997; Gryl, 1995; Klein, 1983; Levelt, 1989; Wunderlich and Reinhelt, 1982). Speakers first need a primary plan that includes a mental representation of the entire area. Using that, they need to determine a route. Then, they need to segment the route and construct procedures for progressing from one segment to the next. Of course, these are the requirements necessary for the speaker alone to get from here to there. The requirement to communicate the route to someone else brings in the nuances of interpersonal communication (e.g., Clark, 1996), the challenge of turning the route into words and gestures that another will understand. The consequent description is typically interactive in two senses: within each participant, there is continual interaction between mental representations of the space and linguistic expressions; between the seeker of directions and the provider of them, there is continuous interaction to make sure the directions are understood.

Denis and his collaborators (Daniel and Denis, 1998; Denis, 1997; Denis and Briffault, 1997; Denis, et al., 1998) are among those who have collected corpora of route directions in the field. Using this corpus, they developed procedures (Denis, 1997) for generating good directions. First, they recoded the individual protocols into standard propositional format and compiled those to create a megadescription. The megadescription was then given to judges familiar with the route, who removed superfluous items. Items included by 70% of the judges were retained in what was termed a skeletal description. In actual navigation, the skeletal descriptions succeeded as well or better than individual protocols rated as good (Denis, et al, 1998). In fact, highly rated protocols were similar to the skeletal descriptions.

What characterises good route directions? Denis' empirically derived prescriptions echo and expand those derived by Wunderlich and Reinelt (1982) and Klein (1983) from linguistic analyses of their corpora, and correspond to Gricean principles (Grice, 1975). Paraphrasing Denis (1997), the essential information is a set of iterative steps:

0 - Locate the listener at point of departure
1 - Start the progression (usually implicit)
2 - Point out a landmark
3 - Reorient listener
4 - Start of progression
Repeat 2-3-4

The steps do not necessarily appear in separate utterances. For example, in three routes on a University campus, Daniel and Denis (1998) found that about 17% of utterances prescribed an action, 36% prescribed an action with respect to a landmark, 33% introduced a landmark, and 12% described a landmark.

Confirming the work of others (e.g., Couclelis *et al*., 1987; Siegel and White, 1975), landmarks seemed to be selected on the basis of visibility, pertinences, distinctiveness, and permanence. They served several functions: to signal the place of action change, to locate other landmarks, and to confirm the route. Similarly, actions were of two types: changes of orientations and continuations in the same direction. The propositions most frequently eliminated by judges as superfluous were those that said to go straight, those that referred to secondary information, and those that described landmarks.

The importance of landmarks or views of critical features in wayfinding is reinforced by research teaching routes by film segments rather than language. Heft (1996) reviews studies in which observers selected the segments of films that were 'most important for finding your way.' The important segments were transitions, that is, changes of orientation, and landmarks. In other studies, participants viewed a selected film of a route and then walked the route, three times. Participants who watched a film of transitions performed better than those who watched a film of vistas between transitions.

Comparing Route Directions and Route Maps

Directions are not the only guide to travelers. Wright *et al*., (1995) found that although wayfinders appreciate maps, informants rarely provide them. Route maps differ in character from area maps, just as route directions differ from spatial descriptions. Route maps, like route directions, include only the information deemed relevant for getting from here to there, excluding other information about the region.

How can route maps be characterised? In order to find out, Tversky and Lee (1998) collected spontaneous route maps and written directions to an off-campus fast food place from passers-by outside a campus dormitory (Tversky and Lee, 1998). Both maps and directions were decomposed into segments following Denis (1997). Each segment ideally contained four kinds of information: start point, reorientation, path/progress, and end point. In examining the results, we first consider necessity followed by sufficiency of the information included in route maps and directions. Then we examine how information is schematised in both.

At least 90% of those providing maps and directions added information over and above the necessary information for progressing from one segment to the next. Maps often included cardinal directions, arrows, distances, and landmarks not at reorientations. Directions included the same extra information and in addition added descriptions of landmarks and paths. The extra information seemed to be designed to assure the travellers that they were on track, and have been found by others (e.g., Denis, 1997; Gryl, 1995). Human communication is not minimalist; in order to succeed, it must contain redundancies and extra information.

To evaluate sufficiency, we examined each segment for the four types of information. All of the maps were sufficient. Technically, the directions had much information missing: 75% lacked either a start or an end point and 45% lacked path/progression information. Discourse frequently lacks information that can easily be inferred from world knowledge (e.g., Clark and Clark, 1977). The missing information could be inferred by invoking two assumptions: continuity and forward progression. Continuity allows the assumption that a missing start point is the same as the previous end point and that a missing end point is the same as the subsequent start point. In fact, except for initial and final points, start and end points are indistinguishable. Forward progression allows inference of the path of progression. Using these two assumptions, all but 14% of the directions reached sufficiency; three of them failed to specify direction of a turn where more than one direction was possible. The medium of drawing precludes some kinds of insufficiency; for example, direction must be specified.

Route maps and route directions schematised information in similar ways (see also Tappe and Habel, 1998 for units of sketch maps). In both, start and end points tended to be landmarks and intersections. In maps, landmarks were represented as icons, usually rough geometric shapes and intersections by more or less perpendicular lines (or line pairs), often labeled, with nouns, as in directions. Reorientations tended to be intersections. In maps, they were accompanied by arrows in nearly half the cases. In directions, reorientations were indicated by a small set of verbs: 'turn,' 'take a,' 'make a,' and 'go,' though verbs were sometimes elided and presupposed, as in 'right on Campus Drive.' In both maps and directions, the angle of turn was unspecified (as in memory for environments, e.g., Byrne, 1979; Moar and Bower, 1983; Tversky, 1981). In maps, paths were represented by lines or line pairs, straight or curved. In directions, 'go' indicated straight paths and 'follow' indicated curved ones. Like the angle of intersection, the curvature of paths is conveyed categorically in both sketches and words.

The similarities in the ways that sketch maps and verbal directions schematise routes are striking. They suggest that the same cognitive schematisation and segmentation underlie both. There are differences, of course, as well. The very nature of the medium renders maps more complete than directions. What must be made explicit in maps is inferred from discourse. Maps are also a more direct mapping of space to space, which may be why wayfinders want them.

In sum.

Spatial language not only provides descriptions of environments and directions to travellers, it also provides a window on spatial cognition. The perspectives used to describe things in space, especially the mixing of perspectives reflect the perspectives, also often mixed, of experiencing things in space (e.g., Behrmann and Tipper, 1998; Bisiach, 1993). The schematisation of space in language and in sketches, what gets included and excluded, what gets simplified and how, reflects the ways the mind schematises space (e.g., Talmy, 1983, 1988). Perhaps because of the ubiquity of spatial experience and spatial language, spatial language is used metaphorically to express concepts from evaluations, as in 'top of the heap' or giving the high five, and moods, as in 'feeling down,' to mathematics, as in graphing, and science, as in models of atoms and molecules.

Old Paths and New Directions

The paths to knowledge of spatial cognition are many, both in kind and in level. The paths leading from spatial cognition are also many, to kinds and levels of behaviour. Spatial cognition is a microcosm of all cognition. It depends on sensation, perception, and memory, and it determines action. It is a consequence of individual differences on the one hand, and of social behaviour, especially language, on the other. It is at once basic to individual and collective existence, necessary for survival, and applied to broad areas of individual and collective enterprise. Spatial cognition underlies the simplest of behaviours and the most abstract imaginations of art and science.

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