



# The semantics of space: Integrating linguistic typology and cognitive neuroscience

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## Abstract

In the cognitive neuroscience literature on the distinction between categorical and coordinate spatial relations, it has often been observed that categorical spatial relations are referred to linguistically by words like English prepositions, many of which specify binary oppositions—e.g., *above/below*, *left/right*, *on/off*, *in/out*. However, the actual semantic content of English prepositions, and of comparable word classes in other languages, has not been carefully considered. This paper has three aims. The first and most important aim is to inform cognitive neuroscientists interested in spatial representation about relevant research on the kinds of categorical spatial relations that are encoded in the 6000+ languages of the world. Emphasis is placed on cross-linguistic similarities and differences involving deictic relations, topological relations, and projective relations, the last of which are organized around three distinct frames of reference—intrinsic, relative, and absolute. The second aim is to review what is currently known about the neuroanatomical correlates of linguistically encoded categorical spatial relations, with special focus on the left supramarginal and angular gyri, and to suggest ways in which cross-linguistic data can help guide future research in this area of inquiry. The third aim is to explore the interface between language and other mental systems, specifically by summarizing studies which suggest that although linguistic and perceptual/cognitive representations of space are at least partially distinct, language nevertheless has the power to bring about not only modifications of perceptual sensitivities but also adjustments of cognitive styles.

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Slus, a Mayan speaker of the language Tzeltal, says to her husband, facing an unfamiliar contraption, “Is the hot water in the uphill tap?” It is night, and we have just arrived at an alien hotel in a distant, unfamiliar city out of the hills. What does she mean? She means, it turns out, “Is the hot water in the tap that would lie in the uphill (southerly) direction if I were at home?” Levinson (2003, p. 4).

## 1. Introduction

There is now a substantial body of evidence supporting the hypothesis, originally formulated by Kosslyn (1987), that the human brain contains separate subsystems for computing two types of spatial relation—coordinate and categorical (for recent reviews, see Jager & Postma, 2003; Laeng, Chabris, Kosslyn, 2003). Representations of coordinate spatial relations involve

precise metric specifications of distance, orientation, and size; they are useful for the efficient visuomotor control of object-directed actions; and they are processed predominantly by the right hemisphere. In contrast, representations of categorical spatial relations involve groupings of locations that are treated as equivalence classes; they serve a variety of perceptual functions, such as registering the rough positions of objects in both egocentric and allocentric frames of reference; and they are processed predominantly by the left hemisphere.

This paper focuses exclusively on representations of categorical spatial relations. It has often been observed that relations of this type are usually referred to linguistically by words like English prepositions, many of which specify binary oppositions—e.g., *on/off*, *in/out*, *left/right*, *above/below*. For instance, Laeng et al. (2003, p. 308) state that “all natural languages seem to have a special class in their grammar (i.e., prepositions) devoted to the expression of categorical spatial relations.” However, the actual semantic content of prepositions (and of other relevant grammatical categories, since prepositions are not the only one) has not been carefully considered

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in most of the cognitive neuroscience literature on categorical spatial relations. The first and most important aim of this paper is therefore to review cross-linguistic research on the semantics of space in order to expose the cognitive neuroscience community to the tremendous diversity, as well as the many overarching commonalities, of the categorical spatial coding systems that are manifested in the 6000+ languages of the world and that are also, *ipso facto*, implemented in the brains of the speakers.<sup>1</sup> These cross-linguistic patterns, which are elaborated in much greater detail elsewhere (e.g. Levinson, 2003; Svorou, 1994) can be regarded as a richly structured body of behavioral data reflecting fundamental aspects of the human neurocomputational architecture for representing and processing categorical spatial relations. The second aim of the paper is to summarize what is currently known about the neuroanatomical correlates of the meanings of spatial terms, with special emphasis on the left inferior parietal lobe, and to suggest some directions for future research. The third and final aim is to address the interface between language and other mental systems, focusing on evidence that while linguistic and perceptual/cognitive representations of space are at least partially distinct, it may still be possible for language to bring about perceptual tuning and cognitive restructuring.

## 2. What types of categorical spatial relations are linguistically encoded?

Very few languages have a word for “space” in the abstract sense employed by philosophers and scientists such as Newton, Leibniz, Kant, and Einstein. However, current evidence suggests that all languages have *Where*-questions (Ulltan, 1978) that tend to elicit answers in which the figure object (F) – i.e., the thing to be located – is described as being within a search domain defined by some kind of categorical spatial relation to a ground object (G)—i.e., a thing that serves as a point of reference (Talmy, 1983). Several classes of categorical spatial relations are encoded to different degrees in different languages, and although they interact in complex ways, each one usually constitutes a fairly independent semantic field that is “carved up” by a specialized set of lexical items and grammatical constructions (Levinson & Wilkins, 2006).

### 2.1. Deictic relations

Deixis involves the many ways in which the interpretation of utterances depends on aspects of the speech event (Fillmore, 1997). In the present context, the most relevant deictic expressions are demonstratives—e.g., *here* versus *there*, *this* versus *that* (Diessel, 1999). These words specify the location of F directly in relation to the location of the speech participants, instead of in relation to some G outside the speech situation. The proper functional characterization of demonstratives requires close attention to details of social interaction (Enfield, 2003). However, I will not discuss these complex social parameters here, since the main

focus is on how demonstratives are often used to divide the egocentric space surrounding the speaker (or addressee) into categorically discrete zones. Crucially, demonstratives do not encode metrically precise degrees of remoteness from the deictic center, but rather have abstract meanings that are pragmatically modulated by either the discourse context or the referential scenario, thereby allowing speakers to flexibly expand or contract the zones so as to express an unlimited range of distance contrasts—e.g., *here in this room* versus *here in this galaxy*.

In a sample of 80 languages from diverse families and geographical regions, Diessel (1999) found that the kind of demonstrative system manifested in English, with a binary proximal/distal contrast, is actually the most frequent, showing up in 44 (55%) of the languages. However, this is the minimal type of system, and other languages exhibit systems of greater complexity. For example, some languages include the addressee as a possible deictic center. Such person-oriented systems come in several varieties. One type, exemplified by Pangasinan (Western Austronesian, Philippines),<sup>2</sup> has a three-way contrast between “near speaker,” “near addressee,” and “far from both speaker and addressee,” while another type, exemplified by Quileute (Chimakuan, Washington State), has a four-way contrast between “near speaker,” “near addressee,” “near both speaker and addressee,” and “far from both speaker and addressee.” These person-oriented systems resemble the English two-term system insofar as they specify just two zones—proximal and distal. The key difference is that person-oriented systems require the speaker to perform more elaborate spatial calculations which take into account not only his or her own egocentric frame of reference, but also that of the addressee. Perhaps for this reason, person-oriented systems are rare, appearing in only 10 languages in Diessel’s sample.

A more common way to increase the complexity of a demonstrative system is to partition the dimension of distance into more fine-grained zones. Twenty-two (27.5%) of the languages in Diessel’s sample follow this strategy by distinguishing between three zones—proximal, medial, and distal. Spanish and Yimas (Sepik-Ramu, Papua New Guinea) have systems like this. A very small proportion of languages go one step further by distinguishing between four zones—proximal, medial, distal, and very distal. Tlingit (Na Dane, Yukon) is the most often cited example. There are even reports of languages with demonstrative systems that encode five distance contrasts (Anderson & Keenan, 1985), but Diessel supports Fillmore (1997), who maintains that systems with more than four terms invariably combine other semantic parameters.

These other semantic parameters include visibility, elevation, and geography. A striking example of how local geographic features can be incorporated into the semantics of demonstrative systems comes from the Himalayan language Limbu (Kiranti, Nepal), which has the following terms: *ma:dha:mbi* means “on the slope of the mountain ridge across the valley from which the speaker is situated,” *kona:dha:mbi* means “on the same slope of

<sup>1</sup> Detailed semantic analyses of particular phenomena in particular languages will not be presented, but for recent studies see Coventry and Garrod (2004) and Carlson and Van Der Zee (2005).

<sup>2</sup> Here and in what follows, the family and geographical area of languages that may not be familiar to the reader are provided in parentheses.

Table 1

Examples of Tzeltal dispositional adjectives encoding topological relations that would normally be described in English as *in* or *on*

Form	Meaning	Eliciting F and G
Ways of conveying “in” relationships involving containment		
<i>T'umul ta</i>	Be located, by having been immersed in liquid in a container	Apple, water in bucket
<i>Tik'il ta</i>	Be located, by having been inserted into a container with a narrow opening	Bull, corral
<i>Xijil ta</i>	Be located, of long-thin object, by having been inserted carefully into a container	Pencils, cup
<i>Xojol ta</i>	Be located, by having been inserted singly into a close-fitting container	Coffee bag, pot
<i>Tz'apal ta</i>	Be located, by having been inserted at its end into supporting medium	Stick, ground
<i>Lapal ta</i>	Be located, of long-thin-sharp object, by having been inserted through a flexible object	Safety pin, cloth
Ways of conveying “on” relationships involving contact with, and support by, a horizontal surface		
<i>Pachal ta</i>	Be located, of a wide-mouthed container canonically “sitting”	Bowl, table
<i>Waxal ta</i>	Be located, of a tall oblong-shaped container or solid object canonically “standing”	Bottle, table
<i>Pakal ta</i>	Be located, of a blob with a distinguishably flat surface lying “face”-down	Dough, table
<i>Lechel ta</i>	Be located, of a wide flat object lying flat	Frying pan, table
<i>Chepel ta</i>	Be located, of a full (bulging) bag supported underneath	Netbag, table
<i>Cholol ta</i>	Be located, of multiple objects arranged in a row	Beans, table

In each case, *ta* is a general-purpose marker meaning “be located”. Data reproduced from Brown (1994).

the mountain ridge as the speaker,” and *khatna:dha:mbi* means either “on the back side of the mountain ridge on which the speaker is situated” or “on the far side of the mountain ridge across the valley from which the speaker is situated” (Van Driem, 1987). Even more remarkable is Cora (Uto-Aztecan, Mexico), which encodes in multimorphemic words the distance of F relative to the speaker (proximal versus medial versus distal), the location of F relative to the speaker’s line of sight (inside versus outside), and the location of F relative to a mountain slope (foot versus face versus top)—e.g., *mah* means roughly “away up there to the side in the face of the slope” (Casad & Langacker, 1985).

## 2.2. Topological relations

According to the loose, non-mathematical sense of “topology” employed in research on spatial semantics, topological relations involve various types of allocentric contiguity between F and G, such as the notions of penetration and containment encoded by the English prepositions *through* and *in*, respectively. In an influential article building on a rich tradition of previous work, Landau and Jackendoff (1993) point out that the spatial concepts found in English prepositions are extremely coarse—in other words, very abstract, schematic, and categorical—since they place few geometric constraints on F and G. They also argue that these sorts of concepts are likely to be cross-linguistically universal. For example, based on the observation that English prepositions are insensitive to the specific shapes of F and G, they state that no language should have a locative element like the hypothetical *sprough*, which means “reaching from end to end of a cigar-shaped object,” as in *The rug extended sprough the airplane*. Similarly, given that English prepositions do not discriminate between the subregions of Gs that are containers, they propose that no language will manifest a locative element like the hypothetical *plin*, which means “contact with the inner surface of a container,” as in *Bill sprayed paint plin the tank*.

This orthodox view has been challenged by studies that have revealed considerable diversity in the kinds of topological relations that are lexicalized in various languages. To begin with the

blackest fly in the ointment, Levinson (2003, pp. 63, 72) notes that the putative non-existence of an expression like *sprough* is directly contradicted by Karuk (Hokan, Northwestern California), which has a suffix *-vara* meaning “in through a tubular space”. Similarly, expressions of the *plin* type, which specify subregions of G, have been attested in Makah (Wakashan, Washington State), which has suffixes encoding locations such as “at the rear of a house,” “at the base of an upright object,” and “at the head of a canoe” (Davidson, 1999). Equally if not more threatening to Landau and Jackendoff’s theory is Tzeltal (Mayan, Southeastern Mexico), which describes topological relations with a large but, importantly, closed class of so-called dispositional adjectives that specify quite detailed, yet still essentially categorical, distinctions involving the location of F relative to G (Brown, 1994). When combined with the single, all-purpose relational marker *ta*, these words extensively cross-classify spatial arrays that would be described in English by using semantically more general prepositions like *in* and *on* (Table 1). Thus, if asked “Where are the tortillas?” an English speaker might reply simply “On the table,” a statement that semantically reduces the tortillas to a mere point or shapeless blob; however, a Tzeltal speaker would probably select one of several terms that encode geometric information about the appearance of the tortillas, such as *latzal* (if they are stacked) or *pakal* (if they are folded).

Although languages differ greatly in the kinds of topological relations they encode, there are underlying patterns. In a recent study, nine unrelated languages<sup>3</sup> were investigated by comparing native speaker responses to a standardized set of 71 pictures showing a wide range of topological relations (Levinson & Meira, 2003). Results indicated that cross-linguistically the labels for pictures were not randomly distributed but instead tended to cluster, suggesting that the topological domain forms a coherent similarity space with a number of strong “attractors,” i.e., taxonomically basic-level categories that are statistically

<sup>3</sup> Basque (Isolate, Europe), Dutch (Indo-European, Europe), Ewe (Niger-Congo, West Africa), Lao (Tai-Kadai, Southeast Asia), Lavukaleve (Isolate, Solomon Islands), Tiriyo (Cariban, South America), Trumai (Isolate, South America), Yéli Dnye (Isolate, Papua New Guinea), Yukatek (Mayan, Mexico).

likely to be recognized by languages—in particular, notions such as containment, attachment, superadjacency, subadjacency, and proximity. Several generalizations about the organization of this abstract similarity space emerged from the study. First, each core concept has a prototype structure. For example, at the center of the cluster of containment pictures were scenes in which F is enclosed within G (e.g., a dog in a cage); scenes involving partial two-dimensional containment on a planar surface (e.g., a dog in a yard) were more peripheral, implying that English is somewhat unusual in using *in* for such topological relations. Second, the core concepts are arranged as neighbors along gradients in the similarity space, making some confluences of categories more natural than others. For instance, English *on* embraces both superadjacency (e.g., a cup on a table) and attachment (e.g., a picture on a wall), Berber *di* embraces both attachment (e.g., a picture on a wall) and containment (e.g., an apple in a bowl), and Spanish *en* embraces all three categories; however, there should not be, and do not as yet appear to be, any languages with a spatial morpheme that applies to superadjacency and containment while excluding attachment, since the latter concept is intermediate between the other two along the relevant gradient of the abstract similarity space (Bowerman & Choi, 2001). Third, each core concept can be further fractionated, leading to more fine-grained categories of topological relations. For example, the cluster of pictures for superadjacency included scenes both with and without contact (e.g., a cup on a table, and a lamp above a table), suggesting that languages are likely to use the same morpheme for these kinds of relations—a tendency that seems somewhat surprising from the perspective of English, since *on* and *above/over* divide the superadjacency category into separate subcategories distinguished by the presence or absence of contact between F and G. Levinson and Meira also report many intriguing cases of category fractionation in other languages, such as the exotic Tiriyo morpheme *awee*, glossed “astraddle,” which applies to the subset of attachment pictures in which F is suspended from a point on G and hangs down on either side of it (e.g., a coat on a hook, an earring dangling from a person’s ear, a pendant on a chain, clothes drying on a line, a balloon on a stick, and a tablecloth on a table).

### 2.3. Projective relations

Projective relations involve locating F within a search domain that radiates out some distance from G along a specified angle or line. This class of categorical spatial relations breaks down into several subclasses, each of which exhibits substantial, but not unconstrained, cross-linguistic variation. The following summary is based mainly on Levinson’s (2003) analysis.

#### 2.3.1. The horizontal plane

According to Levinson (2003, p. 76), languages use, to varying degrees, three frames of reference for encoding (primarily) horizontal projective relations: “the intrinsic system, which projects out a search domain from a named facet of a landmark object; the relative system, which imports the observer’s bodily axes and maps them onto the ground object thus deriving named angles; and the absolute system, which uses a fixed set of bear-

ings or a conceptual ‘slope’ to define a direction from a ground object.”

**2.3.1.1. The intrinsic frame of reference.** The first locative strategy has two steps: the speaker identifies a salient part or facet of G – e.g., the “front” – and then extracts from the designated component an angle which extends outward a certain distance, thereby defining a search domain within which F can be found—e.g., *The ball is in front of the house*. In English this system operates mainly by imposing on G a six-sided, box-like “armature” that yields a front, back, top, bottom, and two lateral (i.e., left and right) sides as the major intrinsic parts. Functional criteria are often used to identify, for instance, the “front” of G based on factors like the typical direction of the perceptual apparatus (for animate entities), the typical direction of motion (for vehicles), or the typical direction of encounter (for houses, TVs, etc.). Some objects resist this decompositional approach because they appear to lack intrinsic asymmetries—e.g., English speakers do not construe trees and mountains as having fronts and backs. But judgments of this nature vary across languages—e.g., in Chamus (Nilo-Saharan, Kenya) the front of a tree is the side it leans toward, or, if it is vertical, the side with the biggest branch or the most branches, and in Kikuyu (Nilo-Saharan, Kenya) the front of a mountain is the side opposite its steepest side (Heine, 1997, p. 13).

It is cross-linguistically common for locative terms employing the intrinsic frame of reference to derive historically from body part terms (Heine, 1997; Svorou, 1994). This can be seen in the English example used above – *The ball is in front of the house* – and in a number of fixed English expressions like *the face of a cliff*, *the mouth of a cave*, *the eye of a hurricane*, *the nose of an airplane*, *the head of a nail*, *the neck of a guitar*, *the arm/leg of a chair*, etc. In many languages, however, the body-part-based intrinsic system is extremely complex, requiring regular linguistically driven visual analysis of the axial geometry as well as the major and minor protrusions of inanimate objects so that the relative appropriateness of different body part terms can be computed instantly on the basis of these inherent properties, i.e., independent of the object’s orientation or the speaker’s viewpoint. Perhaps the best-studied language of this type is Tzeltal (Levinson, 1994), in which even a G as seemingly non-descript as a stone may be assigned a “face,” a “nose,” an “ear,” a “back,” a “belly,” or any of about fifteen other quasi-metaphorical body parts in order to specify that F is located within a search domain projected from one of these facets—e.g., an *s-jol* “head” is a protrusion that can be found at one end of the major axis of G and that has a gently curved, circular outline with only minor concavities on either side.<sup>4</sup>

**2.3.1.2. The relative frame of reference.** To describe spatial arrays in which F is at some remove from G but G is classified

<sup>4</sup> The search domain is always restricted, however, to the region directly adjacent to the designated part of G, because when F is separated from G by a larger distance (even a few inches, in most cases), a different set of locative terms is applied—specifically, terms for cardinal directions, as described in Section 2.3.1.3.

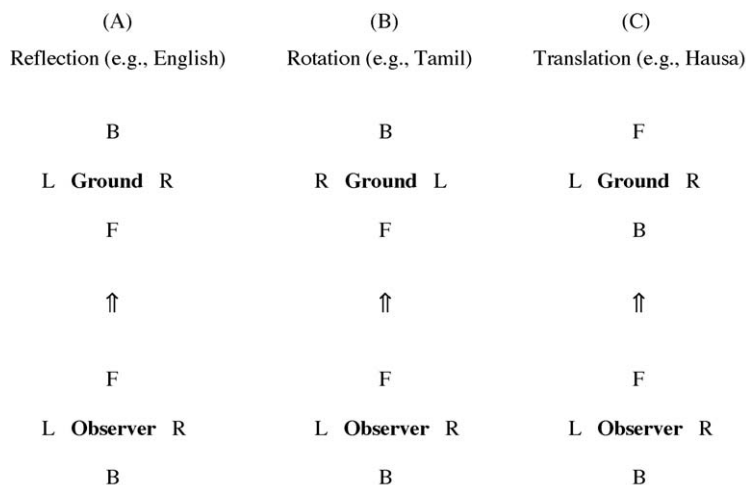


Fig. 1. Cross-linguistic variation in the organization of the relative frame of reference on the horizontal plane. In the illustration of each type of system, the observer is shown at the bottom and the ground object at the top, with the observer's line of sight indicated by an arrow. Abbreviations: F = front, B = back, L = left, R = right. (A) Reflection (e.g., English). (B) Rotation (e.g., Tamil). (C) Translation (e.g., Hausa).

as “unfeatured” by the intrinsic system of the given language, the front/back and left/right axes of the observer's body can be introduced to provide a frame of reference for structuring the scenario. This increases the complexity of the spatial relations from binary (F and G) to ternary (F, G, and the observer). Whereas *The ball is in front of house* specifies a binary relation in which F is located with respect to an intrinsic facet of G, *The ball is in front of the pole* specifies a ternary relation in which F is located with respect to a non-intrinsic facet of G that can only be identified by taking into account the observer's perspective.

The type of relative system found in English involves imposing on G the mirror reflection of the observer's bodily axes (Fig. 1A). A mirror flips the front/back axis but not the left/right axis of the object it reflects. To designate F as being *in front of* or *in back of* G, the observer's front/back axis is mapped onto G under 180° rotation, so that *The ball is in front of the pole* means “From this viewpoint, the ball is in a search domain projected from the side of the pole that ‘faces’ me.” To designate F as being *left* or *right* of G, directions are projected laterally from G along angles that correspond to the observer's left/right axis. Besides the English system, there are two other logical possibilities for organizing the relative frame of reference on the horizontal plane, and both are utilized by other languages (Levinson, 2003, pp. 84–89). One strategy, exemplified by some dialects of Tamil (Dravidian, India), involves mapping the observer's bodily axes onto G under complete 180° rotation, generating not only front/back reversal but also left/right reversal, so that *The ball is in front of the pole* has the same meaning as it does in English, but *The ball is to the left of the pole* means that the ball is located in the region that English speakers would consider “to the right” (Fig. 1B). The other strategy, exemplified by Hausa (Chadic, Nigeria), involves mapping the observer's bodily axes onto G without any rotation whatsoever, so that *The ball is in front of the pole* means that the ball is located in the region that English speakers would consider “in back of,” but *The ball is to the left of the pole* means the same thing it does in English (Fig. 1C).

**2.3.1.3. The absolute frame of reference.** The third type of angular specification on the horizontal plane involves an absolute frame of reference that provides a set of fixed bearings or cardinal directions, similar to north, south, east, and west. These bearings define “an infinite sequence of parallel lines – a conceptual ‘slope’ – across the environment” (Levinson, 2003, p. 90). To indicate the location of F with respect to G, one projects an angle from G to F, assesses the orientation of this angle in relation to the grid of cardinal directions, and selects the appropriate term—e.g., *The ball is north of the pole*. Absolute systems are fundamentally geocentric, and languages often base terms for cardinal directions on stable environmental features like mountain slopes, river drainages, and prevailing wind patterns. For example, returning yet again to Tzeltal, it has an absolute system that is anchored in the mountain incline of the local landscape, giving rise to three directional terms: *ajk'ol* “uphill” (roughly south), *alan* “downhill” (roughly north), and *jejch* “across” (either east or west) (Brown & Levinson, forthcoming). It is important to note (since this issue has been previously misunderstood—see the debate between Li & Gleitman, 2002, and Levinson, Kita, Haun, & Rasch, 2002) that although the terminology of absolute systems derives from environmental landmarks, such systems are fully abstracted, and in order to use them spontaneously and accurately, speakers must constantly monitor their spatial orientation by running a kind of mental compass. This is a remarkable neurocognitive capacity, as revealed by the anecdote about the Tzeltal speaker, Slus, in the epigraph of this paper. Another vital point is that unlike the English *north/south/east/west* system, which has extremely limited use, the absolute systems under discussion are regularly employed to describe spatial arrays at every level of scale, from inches to miles. For instance, Guugu Yimithirr (Pama-Nyungan, Australian) completely lacks words for “left” and “right” directions, so people frequently say things like “Pass the northern cup,” “There's a fly on your southern leg,” etc. (see Levinson, 2003, for extensive discussion).

### 2.3.2. The vertical dimension

Finally, with regard to the linguistic encoding of projective relations along the vertical dimension, the three frames of reference – intrinsic, relative, and absolute – usually coincide and yield the same answer to the question “Where is F in relation to G?” (Levinson, 2003, p. 75). For example, consider a scene in which a fly hovers above a bottle. F is “above” G according to all three criteria: it is located within the search domain that radiates from the top of the bottle (intrinsic frame); it is higher than the bottle in the observer’s visual field (relative frame); and it is higher than the bottle along the vertical axis defined by gravity (absolute frame). However, as a number of experiments have shown (e.g., Carlson-Radvansky & Irwin, 1993; Carlson, 1999; Friederici & Levelt, 1990), the three frames of reference can be manipulated independently of each other (e.g., by rotating either G or the observer, or, more radically, by shifting the entire array to a zero gravity environment) to create special situations in which they yield conflicting answers to the *Where*-question. Also, as noted earlier, although English clearly distinguishes *above/over* from *on* according to whether F contacts G, this may be the result of splitting into two subcategories the cross-linguistically more common (and perhaps conceptually more basic) category of superadjacency, which is neutral with respect to contact and is directly encoded in languages like Japanese and Arrernte (Pama-Nyungan, Australia). This is one of several ways in which the vertical dimension interacts with topology. Another manifestation of this interaction is that *over* and *under* are not synonymous with *above* and *below*, respectively, because the former prepositions have a topological component that makes them more suitable than the latter for describing spatial arrays that involve an encompassment relation—e.g., it is more felicitous to say that a penny is *under* than *below* an inverted cup on a table (Coventry, Prat-Sala, & Richards, 2001).

### 2.4. Summary

Two major generalizations emerge from this review of the kinds of categorical spatial relations that are encoded in languages. First, there is a huge amount of cross-linguistic variation regarding the specific concepts that are lexicalized, suggesting that every language has its own unique spatial ontology with idiosyncratic notions ranging from Limbu’s *ma:dha:mbi* (“F is on the slope of the mountain ridge across the valley from where the speaker is situated”) to Tiriyo’s *awee* (“F is astraddle G”) to Tzeltal’s *ajk’ol* (“F is uphillwards, i.e., roughly south, of G”). Second, despite this tremendous diversity, a number of patterns can be identified that lend coherence to each of the semantic fields comprising the overall conceptual domain. For instance, in the field of deictic relations, over 50% of languages appear to have demonstrative systems that specify a binary proximal/distal contrast; in the field of topological relations, a relatively small number of core concepts tend to recur across languages and hence constitute statistical attractors for lexicalization; and in the field of projective relations, languages typically have complex sets of expressions that instantiate up to three frames of reference—intrinsic, relative, and absolute.

## 3. What are the neuroanatomical correlates of linguistically encoded categorical spatial relations?

Very little research in cognitive neuroscience has explored which brain structures subserve the rich variety of categorical spatial relations that are lexicalized in languages around the world. Nevertheless, all of the studies that have addressed this issue suggest that the left inferior parietal lobe is an especially important cortical region.

### 3.1. Studies implicating the left inferior parietal lobe

#### 3.1.1. Supramarginal gyrus

Damasio et al. (2001) report a positron emission tomography (PET) study in which English speakers viewed drawings of static spatial relations between objects (e.g., a cup on a table) and performed two tasks: naming F, and naming the spatial relation between F and G with an appropriate preposition. When the condition of naming objects was subtracted from that of naming spatial relations, the largest and strongest area of activation was in the left supramarginal gyrus (SMG). The authors do not indicate which prepositions were targeted for production, but it appears that a mixture of topological and projective prepositions were included, which suggests that the SMG activation reflects semantic processing of both types. More recently, a functional magnetic resonance imaging (fMRI) study also found significant SMG activation during a task requiring semantic processing (within the relative frame of reference) of the Dutch equivalents of the terms *left* and *right* (Noordzij, Neggers, Ramsey, & Postma, 2006).

Additional evidence comes from a neuropsychological study conducted by Tranel and Kemmerer (2004); see also Kemmerer and Tranel (2000, 2003). They administered a set of tests that require production, comprehension, and semantic analysis of 12 English prepositions (encoding topological relations as well as several kinds of projective relations) to 78 brain-damaged subjects with lesions distributed throughout the left and right cerebral hemispheres, and then compared the lesion sites of the subjects who were impaired on the tests with the lesion sites of those who were unimpaired. Poor performance was linked with damage in the left SMG and the left frontal operculum. The involvement of the left SMG strengthens the hypothesis that this region plays an essential role in representing the spatial meanings of English prepositions. The investigators did not, however, conduct separate analyses to determine whether the different semantic classes of prepositions dissociate from each other behaviorally and neuroanatomically. As for the involvement of the left frontal operculum, it may reflect either or both of two functions: phonological encoding, possibly in Brodmann area 44 (Amunts et al., 2004), and semantic working memory, possibly in Brodmann areas 45 and/or 47 (Devlin, Matthews, & Rushworth, 2003; Thompson-Schill, D’Esposito, & Kan, 1999; Wagner, Pare-Blagoev, Clark, & Poldrack, 2001).

To my knowledge, no other studies of spoken languages have identified a strong association between the left SMG and morphemes that denote categorical spatial relations; however,

further evidence for precisely this association comes from two functional neuroimaging studies of locative classifier constructions in American Sign Language (ASL; Emmorey et al., 2002) and British Sign Language (BSL; MacSweeney et al., 2002). Locative classifier constructions are complex coding devices that exploit the three-dimensional medium of signing space in the following ways: the relative positions of the hands in front of the body correspond schematically and iconically to the relative positions of F and G in the physical world, and the shape of each hand indicates the general class to which each object belongs (Emmorey, 2003). For example, to express the equivalent of *The bike is near the house*, the referential handshapes for house and bike are articulated sequentially (G preceding F), and then the classifier for vehicles (thumb, middle, and index fingers extended) is placed directly adjacent to the classifier for large bulky objects (five fingers spread and curved) to indicate topographically that F is “near” G. To investigate the neural substrates of this unique form of spatial description, Emmorey et al. (2002) conducted a PET study in which deaf native ASL signers viewed the same kinds of drawings of spatial relations that were used in Damasio et al.’s (2001) PET study, and performed two tasks: naming F, and naming the spatial relation between F and G with an appropriate locative classifier construction. Relative to naming objects, naming spatial relations engaged the left SMG; moreover, the centroid of activation was similar to that found for English speakers in Damasio et al.’s (2001) study, suggesting that it reflects semantic processing. In another study, MacSweeney et al. (2002) used fMRI to investigate the neural systems underlying comprehension of BSL sentences containing locative classifier constructions. Compared to sentences without such constructions, activation was observed in the same sector of the left SMG as in Emmorey et al.’s (2002) study, providing additional support for the hypothesis that this cortical area contributes to the semantic processing of linguistically encoded categorical spatial relations.

### 3.1.2. Angular gyrus

Neuroimaging and neuropsychological studies suggest that the left angular gyrus (AG) is also involved in the linguistic representation of categorical spatial relations, but perhaps to a more limited degree than the left SMG. Baciu et al. (1999) report an fMRI study in which significantly stronger left than right AG activation was observed while subjects judged whether a dot was presented above or below a bar. This task has a core linguistic component because, as the instructions clearly indicate, the two categories that must be discriminated are directly encoded by the projective prepositions *above* and *below*. This particular spatial contrast may seem natural and intuitive to English speakers, but it is by no means cross-linguistically universal, since some languages do not have morphemes that distinguish “above” from “on” or “below” from “in” (Levinson, 2003, p. 73; Levinson & Meira, 2003, p. 507). Hence the left AG activation may reflect, in part, the essentially lexicosemantic process of classifying the location of the dot as falling within one of two projected search domains – “above” or “below” the line – that are both famil-

iar categories in the spatial ontology of the subject’s native language.<sup>5</sup>

Another linguistically encoded categorical spatial contrast that has been linked, albeit loosely, with the left AG is the distinction between *left* and *right* within the intrinsic frame of reference. Lesions centered in the left AG sometimes produce Gerstmann syndrome, which comprises the following four symptoms: left/right confusion, finger agnosia, agraphia, and acalculia (Gerstmann, 1957; Mayer et al., 1999; Mazzoni, Pardossi, Cantini, Giorgetti, & Arena, 1990; Morris, Luders, Lesser, Dinner, & Hahn, 1984; Roeltgen, Sevush, & Heilman, 1983; Varney, 1984). The symptom of left/right confusion is usually manifested as difficulty pointing to left and right body parts on command. However, the relevance of this particular deficit to the issue of the neural correlates of the meanings of *left* and *right* is limited in two ways. First, knowledge of the actual meanings of the terms is not always disrupted; instead, what seems to be impaired are certain cognitive operations that are necessary to apply the meanings appropriately in certain situations, such as the ability to mentally rotate visual images of the body in space (Bonda, Petrides, Frey, & Evans, 1995; Mayer et al., 1999; Zacks, Rypma, Gabrieli, Tversky, & Glover, 1999). For example, Mayer et al.’s (1999) subject performed well (15/16 correct) when asked to point with either hand to designated left and right parts of his own body, but performed poorly (11/16 correct) when asked to point with a specified hand to designated left and right parts of a line drawing of a human body that was facing him and hence had a 180° reversal of left and right sides relative to his own body. Second, studies of Gerstmann syndrome are generally restricted to the use of *left* and *right* to refer to the intrinsic sides of the human body under various conditions; they do not pursue the inquiry further by systematically assessing whether the subject understands how the terms are also used—in English but not in all languages (like Tzeltal and Guugu Yimithirr)—to specify regions of space that are (a) projected outward from the intrinsic sides of the body (e.g., *The ball is on your left*), (b) projected outward from the intrinsic sides of inanimate objects (e.g., *The ball is on the car’s left-hand side*), and (c) projected outward from the sides of unafaceted objects by importing the speaker’s own left/right bodily axis as a frame of reference (e.g., *The ball is to the left of the pole*).

### 3.1.3. A comparative perspective

Brodman’s commonly used map of the human brain distinguishes the inferior parietal lobe (IPL) as areas 39 (AG) and 40 (SMG), but other cytoarchitectonic analyses yield alternative parcellation schemes, usually involving different borders as well as further subdivisions (Zilles, Eickhoff, & Palomero-Gallagher, 2003). Also, while it must be acknowledged that the investigation of areal homologies between human and monkey brains is fraught with difficulties (Bota & Arbib, 2004; Orban, Van Essen,

<sup>5</sup> In a related study, Carlson, West, Taylor, and Herndon (2002) measured event-related brain potentials (ERPs) while subjects judged the appropriateness of *above* for describing the location of a dot relative to a watering can in a series of pictures in which the intrinsic and absolute frames of reference were systematically manipulated.

& Vanduffel, 2004), it is noteworthy that Brodmann's map of the monkey brain contains no areas corresponding to 39 and 40, suggesting that the human IPL is a recently evolved structure. This region has been linked with an astonishingly wide range of operations (see the meta-analysis of 50 neuroimaging studies by Seitz & Binkofski, 2003), but with regard to the specific domain of spatial representation, it may contribute to the relatively long-term coding of spatial relationships for tasks that are apparently beyond the capability of monkeys (Karnath, 2001), such as various forms of complex action planning (Glover, 2004) as well as many kinds of abstract spatial processing (Milner & Goodale, 1995).

### 3.2. Further neuroanatomical questions raised by linguistic typology

The studies reviewed above suggest that the left IPL is a key cortical region for representing the meanings of locative expressions. But when these studies are considered in the context of the preceding typological survey of the kinds of categorical spatial relations that are encoded cross-linguistically, it immediately becomes clear that the research done so far is merely spade-work, and that most of this rich neurocognitive terrain remains to be mined. For example, at this point it is not known whether the three major classes of categorical spatial relations – deictic, topological, and projective – are subserved by separate neural systems within the left IPL. Many questions can also be raised about the specific neural organization of each class, as suggested below.

#### 3.2.1. Deictic relations

I am not aware of any studies that have explored the neural correlates of demonstratives that specify egocentrically-anchored deictic spatial relations, although in a previous paper (Kemmerer, 1999) I pointed out that this topic is interesting in light of the mounting evidence for separate circuits representing, on the one hand, near or peripersonal space which extends roughly to the perimeter of arm's reach, and on the other hand, far or extrapersonal space which extends outward from that fuzzy boundary (Berti & Rizzolatti, 2002). The representational division of near and far sectors of space may derive from computational differences in the forms of sensorimotor control that are typical for each sector—i.e., primarily visually guided manual activity in the near sector, and primarily visual search and object scanning or “parsing” in the far sector. It is tempting to speculate that this fundamental division is causally relevant to the fact that the majority of languages worldwide have demonstrative systems that encode a binary proximal/distal contrast. It is also important to bear in mind, however, that demonstratives are not restricted to quantitative spatial distinctions such as within vs. beyond arm's reach; instead, objective distances are semantic variables that are assigned values on-the-fly by pragmatic factors, thereby allowing speakers to expand or contract the referential range of demonstratives as needed—e.g., as noted by Levinson (1983, p. 80), the statement *Place it here* “may have quite different implications of precision if said to a crane operator or a fellow surgeon.” In addition, some languages

have demonstrative systems that divide the space surrounding the speaker into three or, as in the unusual case of Tlingit, even four distinct zones, thereby violating the two-way perceptual distinction. Perhaps the abstract meanings of demonstratives are subserved by the left IPL, just like the other types of linguistically encoded categorical spatial relations described above. But for demonstrative systems that incorporate geographical information, such as the Limbu and Cora systems involving mountain slopes, the semantic structures may recruit not only the dorsal “where” pathway extending into the left IPL, but also the ventral “what” pathway extending into the inferotemporal cortex (Milner & Goodale, 1995).

#### 3.2.2. Topological relations

Further research on the neural correlates of linguistically encoded topological relations could benefit greatly by utilizing carefully designed stimuli that take into account theoretically important semantic dimensions, like the standardized set of 71 pictures that Levinson and Meira (2003) employed in their cross-linguistic comparison. By conducting high-resolution functional neuroimaging studies with such materials, it may be possible to test the hypothesis that the conceptual similarity space discovered by Levinson and Meira (2003)—a similarity space organized in terms of notions such as containment, attachment, superadjacency, subadjacency, and proximity—is neuroanatomically implemented in the form of a topographically structured cortical map in the left IPL, most likely the SMG. Within this map, the representational dimensions of the conceptual space might be captured, albeit in a warped manner, by the physical distribution of cortical columns (Kohonen & Hari, 1999; Simmons & Barsalou, 2003).

Another reasonable hypothesis is that the inferotemporal cortex contributes to representing the detailed geometric features of objects that Tzeltal incorporates into the meanings of dispositional adjectives (Todd, 2004). Besides encoding various forms of allocentric contiguity between F and G, such as containment or surface contact and support, many dispositional adjectives also indicate, in a manner much more specific than Indo-European languages, the shape or configuration of F relative to G (see Table 1). These terms are semantically similar to the classifiers that are prevalent in sign languages, and Emmorey et al. (2002) report that in their PET study the production of locative classifier constructions engaged not only the SMG but also the left posterior inferotemporal region—a finding which supports the view that the same region might contribute to the geometric component of the meanings of Tzeltal dispositional adjectives.

#### 3.2.3. Projective relations

Projective relations may constitute the subdomain of spatial representation with the greatest potential for interdisciplinary cross-talk between linguistic typology and cognitive neuroscience, because research on the central issue of frames of reference is highly developed in both areas of inquiry (for the best linguistic overview, see Levinson, 2003; for excellent neuroscientific overviews, see Burgess, Jeffrey, & O'Keefe, 1999; Karnath, Milner, & Vallar, 2002; Previc, 1998; Robertson, 2004;

Siegel, Andersen, Freund, & Spencer, 2003; Thier & Karnath, 1997). The direction of influence can certainly go both ways, but here I restrict the discussion to a small sample of the many ways in which recent findings from linguistic typology can generate intriguing questions about the neural substrates of linguistically encoded categorical spatial relations involving intrinsic, relative, and absolute frames of reference.

A major discovery in linguistic typology is that terms for projective relations involving the intrinsic frame of reference often derive historically from body part terms. Moreover, in some languages the application of such terms to the facets of inanimate objects, for the purpose of anchoring a search domain within which F can be located, usually requires a complex visuospatial analysis of axial and contour features—e.g., in Tzeltal an *s-ni* “nose” is a pointed extremity or an extremity having a sharp convexity, and an *x-chikin* “ear” is a flattened protrusion. What is the neural basis of terms like these? One hypothesis is that the meanings of such terms depend on regions of the inferotemporal cortex that receive input from the recently discovered “extrastriate body area” (EBA), which appears to be especially important for the visual categorization of human body parts (Astafiev, Stanley, Shulman, & Corbetta, 2004; Chan, Peelen, & Downing, 2004; Downing, Jiang, Shuman, & Kanwisher, 2001; Urgesi, Berlucchi, & Aglioti, 2004; see also Schwobel & Coslett, 2005).

The fMRI study by Noordzij et al. (2006) implicates the left SMG in the use of *left* and *right* to designate projective relations involving the relative frame of reference. Would the same type of activation be observed when Tamil speakers perform the same task? As noted earlier, Tamil employs a strategy of rotation rather than reflection, so that a sentence like *The triangle is to the left of the circle* means that the triangle is located within a search domain that English (and Dutch) speakers would consider “to the right” (see Fig. 1B).

Perhaps the best example of how linguistic typology can inspire future research on the neural representation of categorical spatial relations involves the systems of cardinal direction terms analogous to *north/south/east/west* that speakers of languages like Tzeltal and Guugu Yimithirr use habitually to specify the angular location of F relative to G according to an absolute frame of reference. Such linguistic behavior requires a mental compass that constantly computes one’s orientation within a conventional framework of fixed bearings. Many non-human species have evolutionarily specialized sensory devices that enable them to use absolute coordinates for navigation—e.g., some species of migratory birds have light-absorbing molecules in their retinæ that are sensitive to the magnetic field of the earth and that may enable the birds to see this information as patterns of color or light intensity (Ritz, Thalu, Phillips, Wiltschko, & Wiltschko, 2004), and sea turtles have the biological equivalent of a magnetically based global positioning system that allows them to pinpoint their location relative to geographically large target areas (Lohmann, Lohmann, Ehrhart, Bagley, & Swing, 2004). But for people in “absolute” communities the mental compass that generates their superb sense of direction—a sense comparable in accuracy to that of homing pigeons (Levinson, 2003, p. 232)—is presumably not genetically programmed but may

instead be a “knock-on” effect of the intensive training in orientation tracking that comes with speaking a language that regularly employs cardinal direction terms to describe spatial arrays at every level of scale (Levinson, 2003, p. 278). It is reasonable to suppose that relevant brain areas include parietal and hippocampal structures that have been implicated in both constructing landmark-based cognitive maps of the environment and monitoring one’s movement through them (Ekstrom et al., 2003; Janzen & van Turenout, 2004). However, because the use of the mental compass does not require input from visually perceived landmarks (as illustrated in the epigraph of this paper), other neural systems must also be recruited, presumably to carry out the computations that underlie dead-reckoning—that is, keeping track of distances traveled along each angular heading.

### 3.3. Summary

Research on the neuroanatomical substrates of linguistically encoded categorical spatial relations has only recently begun, but the studies conducted so far consistently point to the left IPL as an essential region. Taking into account the view from linguistic typology, which provides not only a well-developed theoretical framework but also detailed semantic analyses of the variety of spatial coding systems manifested in the languages of the world, can lead to many new questions regarding the neural basis of this rich conceptual domain.

## 4. How do linguistically encoded categorical spatial relations interact with perception and cognition?

The final topic of discussion involves the interaction between linguistic and perceptual/cognitive representations of categorical spatial relations. Very little is currently known about the nature of this interaction, but the existing data suggest that it is quite complicated. Two main points are elaborated below. First, several studies with both normal and brain-damaged populations indicate that the kinds of categorical spatial distinctions that are encoded for non-linguistic perceptual/cognitive purposes are to some extent separate from the diverse spatial categorization systems of languages around the world. Second, a number of other studies suggest that the unique spatial ontology of one’s language nevertheless has the power to influence one’s perceptual/cognitive representations of categorical spatial relations by both *decreasing* sensitivity to distinctions that are not captured by one’s language and *increasing* sensitivity to distinctions that are. The fact that these two sets of findings are not easy to reconcile is a clear sign that we are still far from understanding the intricacies of the interaction between linguistic and non-linguistic representations of space.

### 4.1. Linguistic and perceptual/cognitive representations of categorical spatial relations are to some extent distinct

Although English distinguishes *on* from *above/over*, many other languages—perhaps even the majority (Levinson & Meira, 2003)—have morphemes that encode the general notion of superadjacency, which is neutral with respect to whether F contacts

G. Korean is one such language. To investigate whether this form of cross-linguistic variation influences non-linguistic spatial memory, Munnich, Landau, and Doshier, 2001 asked native speakers of English and Korean to perform two tasks with the same stimuli, which consisted of spatial arrays showing a ball in any of 72 locations superadjacent to a table. In the naming task, subjects completed the sentence “The ball is. . .the table” (or the equivalent sentence in Korean). In the memory task, they viewed an array for 500 ms, and then after a 500 ms delay they saw another array which they judged as being either the same as or different from the initial one. In the naming task the English speakers consistently employed the lexical contrast between *on* and *above/over*, whereas the Korean speakers rarely mentioned the contact/non-contact distinction. In the memory task, however, the two subject groups had almost identical patterns of accuracy for all 72 locations, including an advantage for locations aligned with the surface of the table. This study therefore suggests that non-linguistic spatial memory is not constrained by whether the contact/non-contact distinction is linguistically encoded on a regular basis throughout one’s life. In other words, even though Korean does not force speakers to fractionate the category of superadjacency according to the presence or absence of contact between F and G, this spatial distinction is nevertheless perceptually salient enough to influence the operation of recognition memory in Korean speakers.

Neuropsychological data also support the view that linguistic and perceptual/cognitive representations of categorical spatial relations are at least partially separate. As noted earlier, Tranel and Kemmerer (2004) found lesion overlap in the left SMG for a group of brain-damaged subjects who had pervasive defects in their knowledge of the meanings of English prepositions. In a follow-up experiment with these subjects, non-linguistic visuospatial processing was assessed by administering a battery of standardized neuropsychological tests, including three subtests from the Wechsler Adult Intelligence Scale-III (Matrix Reasoning, Block Design, and Object Assembly), the Benton Facial Recognition Test, the Benton Judgment of Line Orientation Test, the Hooper Visual Organization Test, the Complex Figure Test (copy), and the Benton Three-Dimensional Block Construction Test (Benton & Tranel, 1993; Tranel, 1996). Overall, the subjects performed extremely well on the various tests. Although two of the tests – the Benton Facial Recognition Test and the Benton Judgment of Line Orientation Test – emphasize sensitivity to coordinate spatial relations, the remaining tests arguably require an appreciation of categorical spatial relations (see Kemmerer & Tranel, 2000, for further discussion).<sup>6</sup> Moreover, Kemmerer and Tranel (2000) describe a subject with a large right-hemisphere lesion affecting frontoparietal and temporal regions who manifested a dissociation that was the opposite of the kind manifested by the brain-damaged subjects in Tranel and Kemmerer’s (2004) study—namely, intact knowledge of the meanings of English prepositions but impaired non-linguistic visuospatial process-

ing of coordinate as well as categorical spatial relations. Taken together, these findings constitute evidence for what Jager & Postma (2003, p. 513) call “a tripartition between perceptual coordinate spatial codes, perceptual categorical spatial codes, and verbal categorical spatial codes.”

Additional neuropsychological evidence for this “tripartition”—the most interesting aspect of which involves the distinction between the two subclasses of categorical spatial codes, verbal and perceptual—comes from Laeng (1994), who evaluated the performance of 60 brain-damaged subjects, 30 with unilateral left-hemisphere (LH) lesions and 30 with unilateral right-hemisphere (RH) lesions, on the following tasks. First, subjects were shown a drawing of two objects bearing a certain spatial relation to each other (e.g., a large cat to the left of a small cat), and after a short delay they were shown another drawing and were asked to make a same/different judgment (analogous to the recognition memory task in Munnich et al.’s 2001 study); half of the drawings were different, and the change was along either the categorical dimension (e.g., a large cat to the right of a small cat) or the coordinate dimension (e.g., a large cat to the left of a small cat, but a different distance away). Second, once again subjects were shown a drawing of a spatial relation, but this time after a short delay they were shown two other drawings and were asked to decide which was more similar to the initial one; alterations were either categorical or coordinate. On both tasks, LH-damaged subjects had greater difficulty detecting categorical than coordinate changes, and RH-damaged subjects exhibited the opposite pattern. What is most important in the present context, however, is that Laeng (1994) also found that the LH-damaged subjects’ scores on several aphasia tests—including the Token Test, which has commands that incorporate prepositions (e.g., “Point to the square to the left of the blue circle”)—did not correlate with their scores on the non-linguistic spatial tests. This implies that among the LH-damaged subjects who were impaired on the test involving perceptual categorical spatial codes, there were some who nevertheless performed well on the test involving verbal categorical spatial codes. The study therefore provides further support for the view that linguistic and perceptual/cognitive representations of categorical spatial relations are to some extent distinct. Further research is clearly necessary, however, to explore the nature of this distinction in greater detail.

#### 4.2. *Linguistic representations of space can influence perceptual/cognitive representations of space*

The studies reviewed above suggest that the kinds of categorical spatial distinctions that are encoded for non-linguistic purposes are at least partially separate from the spatial ontology of one’s language. However, a number of recent studies suggest that language can nevertheless influence perceptual/cognitive representations of space by modulating sensitivity to certain distinctions. These studies support the “Whorfian hypothesis” that language modifies thought—a hypothesis that was widely embraced during the 1950s and 1960s, fell into disrepute during the 1970s and 1980s, and was resurrected in the mid-1990s

<sup>6</sup> An important caveat, however, is that none of the tests was specifically designed to distinguish between impaired processing of categorical spatial relations and impaired processing of coordinate spatial relations.

because of theoretical and methodological advances that have continued to develop (Gentner & Goldin-Meadow, 2003).

#### 4.2.1. *Language can decrease sensitivity to certain categorical spatial distinctions*

As summarized above, Munnich et al. (2001) found that even though Korean does not lexicalize the contact/non-contact distinction, speakers are still sensitive to it for non-linguistic purposes such as recognition memory. However, there is also evidence that in some cases sensitivity to a particular categorical spatial distinction is present in infancy but then gradually diminishes during an early stage of language acquisition because the distinction is not captured by the target language being learned. This type of scenario is illustrated by a study that focused on the following contrast between English and Korean strategies for describing actions involving topological relations of containment (McDonough, Choi, & Mandler, 2003). The English expression *put in* specifies that F ends up occupying an interior region of G, but is neutral with respect to whether F fits tightly or loosely within G. In Korean, on the other hand, the notion of containment is subdivided into two different categories: *kkita* designates the creation of a tight-fitting relation between F and G (e.g., putting a cassette in a case), and *nehta* designates the creation of a loose-fitting relation between F and G (e.g., putting an apple in a bowl). Using a preferential looking paradigm as an indirect measure of perceptual categorization, McDonough et al. (2003) found that infants as young as 9 months of age, from both English- and Korean-speaking environments, can discriminate between tight and loose containment events (see also Hespos & Spelke, 2004). This kind of spatial sensitivity is clearly useful for infants growing up in Korean-speaking environments, but it is ultimately less valuable for infants growing up in English-speaking environments, and in fact when adult speakers of each language were given the same preferential looking task, the Korean speakers exhibited sensitivity to the tight/loose distinction, but the English speakers did not. In another experiment that evaluated the adult speakers' recognition of the distinction more explicitly, subjects observed the enactment of three tight containment events and one loose containment event, and then answered the question "Which is the odd one?" Significantly more Korean- than English-speaking adults based their choice on degree of fit (80% versus 37%).

The investigators interpret their findings as evidence that when language-specific spatial categories are being learned, the perceptual judgments that are necessary to use them efficiently become increasingly rapid and automatic. Thus Korean speakers implicitly monitor the tightness of fit of containment relations because the grammatical system of their language regularly forces them to encode distinctions along this parameter. However, spatial sensitivities that are not needed in order to use the local language may fade—e.g., English speakers can safely ignore the tight/loose contrast most of the time. As McDonough et al. (2003) point out, the loss of sensitivity to the tight/loose contrast is remarkably similar to another dramatic instance of perceptual tuning that takes place during early language development, namely the loss of phonetic contrasts that are not phonemic in the target language (Kuhl, 2004; Kuhl, Williams, Lacerda,

Stevens, & Lindblom, 1992; Werker & Tees, 1984; see also Jacquemot, Pallier, LeBihan, Dehaene, & Dupoux, 2003). More generally, the fact that these and many other forms of categorical perception are subserved predominantly by the left hemisphere is consistent with the proposal that this hemisphere has an innate bias for focusing attention on discrete regions of input (possibly by means of neurons with relatively small, non-overlapping receptive fields), thereby causing many distinct subsystems to become "yoked" together via a developmental "snowball" process (Jacobs & Kosslyn, 1994; Kosslyn, 1987; Kosslyn, Sokolov, & Chen, 1989; Van Kleeck & Kosslyn, 1991; see also Ivry & Robertson, 1998).

Linguistically induced downgrading of spatial acuity is also illustrated by Levinson's (2003, pp. 152–154) report that Tzeltal speakers have great difficulty distinguishing mirror stimuli—e.g., b versus d. This intriguing perceptual deficiency may derive from the fact that Tzeltal makes no use of the egocentrically anchored relative frame of reference, relying instead on two other locative strategies (apart from dispositional adjectives for describing topological relations): body-part terms based on the intrinsic frame of reference for describing closely contiguous projective relations, and directional terms based on the absolute frame of reference for describing more distant projective relations. Because the mirror stimuli employed in the experiment were multicomponent line figures, they were most likely processed according to the intrinsic system, which is essentially orientation-free and viewer-independent. The Tzeltal speakers' difficulty in detecting the difference between unreflected and reflected images cannot be attributed to low education, since educationally matched speakers of Totonac, a Mayan language that does use the relative frame of reference, performed the task much like Dutch speakers. From the perspective of cognitive neuroscience, it is striking that the behavior of the Tzeltal speakers resembles that of brain-damaged English and Italian speakers who have selectively impaired mirror-stimulus discrimination (Davidoff & Warrington, 2001; Priftis, Rusconi, Umiltà, & Zorzi, 2003; Turnbull & McCarthy, 1996). A direction for future research would be to carefully compare the presumably linguistically induced decrement in discriminating mirror stimuli exhibited by Tzeltal speakers with the clearly neurologically induced form of mirror stimulus agnosia exhibited by brain-damaged subjects.

#### 4.2.2. *Language can increase sensitivity to certain categorical spatial distinctions*

There are also reasons to believe that language can cause speakers to become more attuned to particularly subtle or non-obvious types of spatial relationships. According to Bowerman & Choi (2003, p. 417), "In cases like this, an important stimulant to comparison can be hearing the same word. As the child encounters successive uses of the word, she 'tries' (although this process is presumably rarely if ever conscious) to align the referent situations and work out what they have in common. Sometimes...there is no existing concept that does the job, and the child has to construct a new one to account for the distribution of the word." An excellent example is the Tiriyó morpheme *awee* which refers to situations in which F is sus-

ended from a point on G and hangs down on either side of it, hence treating as equivalent such superficially diverse spatial arrays as a necklace around a person's neck, a tablecloth draped over a table, and a clothespin dangling from a line (see Section 2.2). It is not known whether infants are sensitive to this highly language-specific spatial category, but it seems likely that they are not and that they must therefore gradually construct the concept through multiple exposures to *awee* when acquiring Tiriyó. Another good example is the Chamus strategy of treating the intrinsic front of a tree as either the side it leans toward or, in case it is perfectly vertical, the side with the biggest branch or the most branches (see Section 2.3.1.1). It seems safe to assume that these are features of trees that English speakers do not usually register, although Chamus speakers must attend to them in order to use the grammatical system of the language appropriately. In this manner language can be said to provide “on-the-job training for attention” (Smith, Jones, Landau, Gershkoff-Stowe, & Samuelson, 2002). As Majid (2002) observes, it is useful to think of this form of linguistically driven perceptual tuning as similar to the novice-to-expert shift in categorization abilities that is known to engender more refined representations for the target domain (Palmeri, Wong, & Gauthier, 2004).

The most systematic and intensive investigation of linguistic influences on cognitive representations of space has been conducted by Stephen Levinson and his colleagues (e.g., Levinson, 2003; Majid, Bowerman, Kita, Haun, & Levinson, 2004; Pederson et al., 1998). Although this area of inquiry is highly controversial (see the debate between Li & Gleitman, 2002, and Levinson et al., 2002), several experiments suggest that there are deep cognitive consequences of speaking a language that employs predominantly either the relative frame of reference, like English and Dutch, or the absolute frame of reference, like Tzeltal and Guugu Yimithirr, for describing projective relations. The central experimental method involves a rotation paradigm which makes it possible to identify the frame of reference that subjects use to carry out various types of non-linguistic cognitive tasks, such as memory tasks that probe both recognition and recall, maze tasks that require tracking motion and path direction, and reasoning tasks that evaluate transitive inference. To take a straightforward example, subjects are first seated at a table on which three toy animals are lined up headed *leftward*, or *south*, and then they are rotated 180° and seated at a different table where they must arrange an identical set of toy animals so that they are just as before. The task instructions place an emphasis on remembering linear order as opposed to direction. If subjects orient the animals in a leftward direction, they are invoking an egocentric frame of reference, but if they orient the animals in a rightward (i.e., southerly) direction, they are invoking an absolute frame of reference. When performing this as well as all other non-linguistic cognitive tasks involving the rotation paradigm, subjects overwhelmingly follow the coding pattern of their language. Such results have been obtained with speakers of a variety of “relative” languages—e.g., English, Dutch, Japanese, and Yukatek (Mayan, Mexico)—and “absolute” languages—e.g., Tzeltal, Guugu Yimithirr, Arrernte, Hai//om (Khoisan, Namibia), Longgu (Austronesian, Solomon

Islands), Balinese (Austronesian, Indonesia), and Belhare (Sino-Tibetan, Nepal).

Levinson (2003, pp. 290-1) argues that these effects are due to the fact that relative and absolute frames are incommensurable—e.g., from the proposition “The knife is to the right of the fork” one cannot derive the proposition “The knife is to the south of the fork,” or vice versa:

Once a language has opted for one of these frames of reference and not the other, all the systems that support language, from memory, to reasoning, to gesture, have to provide information in the same frame of reference. If I remember an array as “The knife is to the right of the fork” but live in a community where no left/right terminology or computation is part of everyday life, I simply will not be able to describe it. For my memory will have failed to support the local description system, in, say, terms of north and south. The use of language thus forces other systems to come into line in such a way that semantic parameters in the public language are supported by internal systems keeping track of all experience coded in the same parameters.

Despite Levinson's assertions, this area of research remains quite contentious. Nevertheless, there is sufficient data to motivate questions regarding the neural substrates of linguistically driven cognitive restructuring. For example, although neuropsychological studies have shown that some brain-damaged subjects with impaired knowledge of the meanings of English prepositions can still accomplish tasks requiring non-linguistic processing of categorical spatial relations (Kemmerer & Tranel, 2000; Tranel & Kemmerer, 2004), it is unknown how such subjects would perform on the various kinds of non-linguistic “space games” that Levinson and his colleagues have developed around the rotation paradigm. How would an English-speaking brain-damaged subject with severely disrupted knowledge of *left* and *right* perform on the “animals in a row” task described above? And what would the results reveal about the interface between linguistic and cognitive representations of space? These questions, and many others that involve integrating linguistic typology and cognitive neuroscience, await future research.

#### 4.3. Summary

Experimental studies with normal as well as brain-damaged subjects suggest that the meanings of locative expressions are language-specific semantic structures that are activated primarily when a person packages his or her conceptualizations of space in a manner that can easily be communicated in words—a process that Slobin (1996) calls “thinking for speaking.” These linguistic representations are at least partially distinct from the perceptual/cognitive representations used in many visuospatial and visuomotor tasks such as recognizing, drawing, and constructing complex spatial arrays. At the same time, however, recent findings from the neo-Whorfian movement suggest that the unique way in which one's language structures space has implications for other mental systems, bringing about not only modifications of perceptual sensitivities but also adjustments of cognitive styles. I consider it a safe bet that most if not all

of the readers of this article are usually *oblivious* to their orientation with respect to north, south, east, and west; however, there are a great many cultures in which people can *instantly* indicate cardinal directions like these. Such profound cognitive differences may be largely due to linguistic differences. The correct theory of the interface between linguistically and non-linguistically encoded categorical spatial relations remains a topic of future research, but I suggest that the most progress will be made through interdisciplinary efforts that include the mutually informing perspectives of linguistic typology and cognitive neuroscience.

## 5. Conclusion

People worldwide talk on a daily basis about the three-dimensional spatial world that surrounds them, and most of the time the content of their discourse concerns broadly defined spatial categories—e.g., *The book is right here in front of me*—as opposed to metrically exact notions—e.g., *The book is 53 cm from my chest*. This is obviously a natural state of affairs. After all, coordinate details usually cannot be consciously quantified with precision, and even if they could be, taking them into account in ordinary linguistic communication would require an astronomical number of locative morphemes to express all of the possible spatial relations—a situation that would be computationally unmanageable and pragmatically otiose, not to mention utterly impossible in languages that completely lack the lexical and grammatical resources for complex counting (Gordon, 2004). But even though almost all spatial discourse is restricted to schematic, coarse-grained distinctions, there is nevertheless a vast range of coding possibilities, and languages vary tremendously in how they carve up this multidimensional conceptual domain, while still conforming to certain overarching tendencies. The main goal of this paper has been to introduce this rich field of semantic diversity to cognitive neuroscientists interested in spatial representation, and to suggest ways in which cross-linguistic data can help guide future research on how linguistically encoded categorical spatial relations are implemented in the brain, and on how they interact with perceptual/cognitive representations of space. The upshot of the paper is captured by the following question: Would research on the neural substrates of spatial representation be substantially different if the dominant language in the world were, say, Tzeltal instead of English?

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