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Spatial semantics: Modeling the meaning of prepositions

Joost Zwarts

Utrecht University, Utrecht, The Netherlands

Correspondence
Joost Zwarts, Utrecht University, Trans 10, 3512 JK Utrecht, The Netherlands.
Email: j.zwarts@uu.nl

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Abstract

Reference to space, especially with prepositions, plays a central role in natural language and is receiving more and more attention over the past decades. One line of research uses formal semantic modeling, using topological and other geometrical concepts such as regions, vectors, and paths. Another line of research has drawn attention to the role of function, force-dynamics, polysemy, prototypes, and crosslinguistic variation in this domain. This paper gives an overview of both lines of research and argues that a synthesis is possible, based on a proper division of labor between semantics and pragmatics, richer ontologies, and a perspective on categorization that uses conceptual spaces and semantic maps.

1 | INTRODUCTION

Space is one of the most fundamental domains in natural language, encompassing a variety of closely related properties, such as location, path, size, shape, and orientation. An important part of spatial language involves the description of where something is or how it is moving, typically (at least in English) with prepositions such as *in*, *behind*, *from*, *through*. The systematic study of the meaning of such items, and other spatial expressions, can be referred to as *spatial semantics*. One natural approach is to take spatial semantics as applied geometry, by interpreting prepositions in terms of elements and relations in some mathematical model. I start my overview in Section 2 with that approach, which is characteristic for *formal semantics*. However, much work from psychology and linguistics seems to challenge this simple geometric approach, and certain claims sometimes associated by it, by demonstrating the role of various non-geometric factors, the ubiquity of polysemy, and the importance of crosslinguistic variation. This approach, typical of so-called *cognitive semantics*, is the topic of Section 3. After the formal 'thesis' and the cognitive 'antithesis', I discuss the possibility of a 'synthesis' in Section 4.

2 | FORMAL THESIS: GEOMETRIC MODELS OF SPATIAL MEANING

2.1 | Places and paths

Consider the following two sentences:

1.
   a. The cat was on the mat.
   b. The cat jumped onto the mat.

On is a locative preposition (like *in*, *at*, *under*, *behind*, …) and *onto* a directional preposition (like *from*, *to*, *towards*, *across*, …). One could treat these prepositions as based on a direct relation between the cat and the mat, which, following Talmy (1985), can be called *figure* (located object, locatum, or trajector) and *ground* (reference object, relatum, or landmark). This direct relation holds throughout the described situation in 1a, and only at the end of the situation in 1b, which is sometimes expressed using the BECOME operator (that expresses that the state of the cat being on the mat comes about).

2.
   a. ON(THE-CAT,THE-MAT)
   b. BECOME(ON(THE-CAT,THE-MAT))

Such a relational approach is what we see in earlier formal work on spatial prepositions (e.g., Dowty, 1979; Miller & Johnson-Laird, 1976; Sondheimer, 1978). In later work, the preposition in 1a is usually broken up in two parts. There is a function that maps the ground to a spatial meaning, a *place*, *location*, or *region* ON(THE-MAT), and there is a general location relation BE (possibly expressed by the copula) between the figure and that region.

3.
   a. BE(THE-CAT,ON(THE-MAT))
   b. GO(THE-CAT,ONTO(THE-MAT))

Representation 3a is the type of representation for locatives that we find most prominently in the work of Jackendoff (1983), but also in Herskovits (1986), Bierwisch (1988), Wunderlich (1991), for instance. Making the spatial nature of the Prepositional Phrase (PP) explicit has several advantages (Creary, Gawron, & Nerbonne, 1989). Verbs can take locations as arguments (*put on the mat*), spatial anaphors can pick them up (*there, on the mat*), adverbs and measure phrases modify them (*right on the mat*, Zwarts, 1997). In the same way, the function ONTO in 3b can be treated as mapping the mat to something spatial, in this case a *path* or *trajectory*, the final destination of which is the surface of the mat. As shown in 3b, the figure traversing the path is not an argument of the preposition but of a predicate GO that expresses motion. This approach puts the transition from 'not on' to 'on' in the spatial domain, and not in a temporal BECOME operator or in the event structure of the sentence (as in Higginbotham, 2009). In addition to the advantages for argument selection, modification, and reference that we already mentioned, paths can also more easily be generalized to nonmotion uses of directional prepositions, such as when we talk about a road extending towards or across a village (Gawron, 2006; Jackendoff, 1983; Talmy, 1996).

In order to make the spatial nature of a PP fully explicit, it is useful to treat its meaning as a *set* of spatial entities, existentially quantified over in the sentence:

4.
  a. $\exists p$ [$p \in$ ON(THE-MAT) & BE(THE-CAT,p)]
  b. $\exists p$ [$p \in$ ONTO(THE-MAT) & GO(THE-CAT,p)]

Under this analysis, 1a says that there is a place on the mat where the cat is, and 1b says that there is a path onto the mat that the cat is following. This is just a general spatial skeleton, of course. The main question in formal spatial semantics is how to model places and paths in such a way that the contribution of prepositions to the truth conditions and entailment patterns of the sentences they occur in can be accounted for in a compositional way. On the one hand, this involves defining how prepositions such as *on* and *in*, *under* and *over*, *onto* and *off*, *across* and *around* are distinguished from each other; on the other hand, it requires an account of the semantic relationships between prepositions such as *on* and *onto* and *in* and *through*. For example, sentence 1a will typically be true in a different set of situations than those in which sentence 5a below is true, because *on* requires contact between figure and ground, whereas *above* does not (see also Figure 1).

5.
  a. The cat was above the mat.
  b. The cat jumped onto the mat. ⇒ The cat was on the mat.

The role of entailment is illustrated in 5b. If the first sentence is true then the second sentence must also be true, because there cannot be an *onto* path, without there being a final *on* location (see Figure 1), unless there are independent reasons why this endpoint might not be reached, particularly with imperfective aspect.

The relationship between places and paths is asymmetric. The concept of a path cannot be properly understood without the more basic concept of a place. A path expression can therefore often be analyzed as built on an explicit or implicit place concept. This is an important insight, going back at least to Gruber (1965), well-represented in the analyses of English prepositions in Bennett (1975) and Jackendoff (1983), and applied in a variety of detailed analyses of prepositional and case systems (Talmy, 1985, Koopman, 2000, Kracht, 2002, Svenonius, 2008, den Dikken, 2010, Gehrke, 2008, Lestrade, 2010, Zwarts, 2010a, Pantcheva, 2010). We can represent this as follows:

6. path(place(ground))

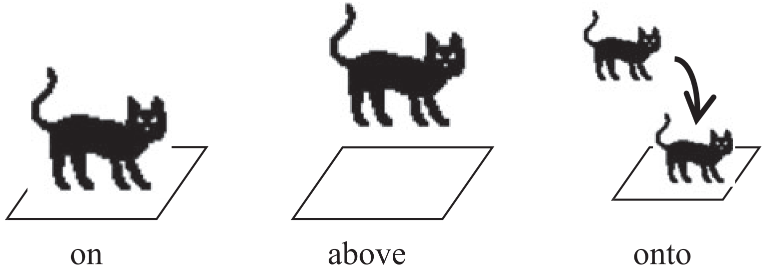


FIGURE 1 The cat on, above, and onto the mat

The place component is also called configuration, location, or localizer, the path component direction, mode, or modalizer. This then leads to the following pair of representations for 1a and 1b. ON applies first to the ground (the mat in this case), giving a set of places, and TO applies to that, giving a set of paths that have as their endpoint an ON place.

7.
  a. $\exists p$ [$p \in$ ON(THE-MAT) & BE(THE-CAT,p)]
  b. $\exists p$ [$p \in$ TO(ON(THE-MAT)) & GO(THE-CAT,p)]

2.2 | More on places

Because the domain of places is more basic, let us focus on place prepositions first. Two basic models for places can be distinguished, *regions* and *vectors*, and, as we will see, these two ways correspond in a sense to the two major types of spatial prepositions distinguished in the literature, the *topological* and the *projective* prepositions.

Places can be treated as *regions* of space. One possibility is to assume a three-dimensional set of mathematical points as given and then construct regions as sets of points (Kracht, 2002). However, it is much more common to take a *qualitative*, *mereological* approach to regions, that is, to take them as primitives. One of the reasons is that mathematical points are thought to be too precise for modeling the role of places in semantics. This is the approach of Bierwisch (1988), Wunderlich (1991), Aurnague and Vieu (1993), Aurnague (1995), Nam (1995), Gambarotto and Muller (2003), and Coventry and Garrod (2004), among others. It is on the one hand strongly related to the algebraic approach to verbal and nominal denotations, where intervals, events, and sums are taken as primitives (e.g., Krifka, 1998). On the other hand, there are close connections with work on spatial ontology in theoretical philosophy and practical applications (see Bateman, Hois, Ross, & Tenbrink, 2010 for a general treatment), in particular with the so-called Region Connection Calculus (Cohn, Bennett, Gooday, & Gotts, 1997). This calculus assumes one primitive relation of *connection* between regions (two regions connect if they overlap or touch) from which a range of other relevant relations can be derived, such as those in Figure 2.

One can see already how notions such as ‘contiguity, contact’ (for *on*) and ‘inclusion, enclosure’ (for *in*) that appear in many descriptions of these prepositions find a place in this system. The function ON in 7a can then be defined as a function from the region of the ground to the set of regions that are externally connected with it, *in* will involve the proper part, and *above* is disconnected.

Clearly, in order to capture place relations beyond *on* and *in* more is needed, in particular, notions of *distance* and *direction* have to be added. Different ways of doing this in the context of prepositional semantics are discussed in Aurnague and Vieu (1993), Nam (1995), and Gambarotto and Muller (2003). Nam (1995) assumes two three-place relations, NEARER(x,y,z) for ‘x is nearer to y than z is’ and BETWEEN(x,y,z) for ‘y lies between x and z’ for this purpose. The former relation allows for the

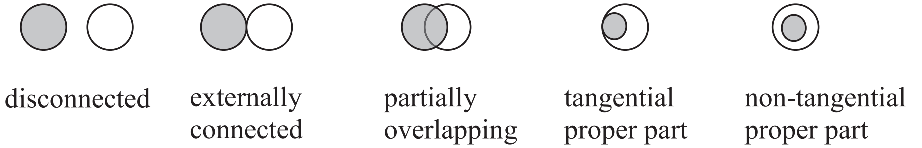


FIGURE 2 Different spatial relations in RCC based on connection

definition of expressions such as *near* and *far*, the latter relation for *between* and for *above* and *behind* (assuming that the up-down and front-back axis are specified in the appropriate way).

A quite different way of representing places starts with distances and directions, combining these in the notion of a *vector*. Three-place relations such as 'nearer' and 'between' are then definable in terms of vectors: 'x is nearer to y than z is' involves a comparison of the length of the vectors between x, y, and z, 'y lies between x and z' a comparison of their directions. The idea of vectors came up independently from two research directions. O'Keefe (1996) took the idea of a vector-based representation for prepositions from his work on the role of the hippocampus as a 'map' in animal navigation. Zwarts (1997) and Zwarts and Winter (2000) introduced vectors to allow for a compositional interpretation of modified PPs, such as *three feet above the mat*. It is the last version of a vector-based semantics that I discuss here.

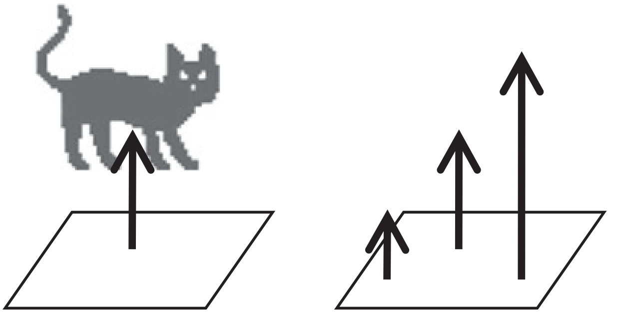
Recall that we take a locative preposition as a function from a ground object to a set of spatial places, one of which is the position of the figure, as illustrated in 8:

8.
   a. The cat is above the mat.
   b. $\exists p$ [$p \in$ ABOVE(THE-MAT) & BE(THE-CAT,p)]

In vector-based semantics, the spatial variable p ranges over vectors: the situation in 8 is represented by one vector that points from the mat to the cat (see Figure 3a). The expression ABOVE(THE-MAT) corresponds to the set of all vectors that point upward from the mat (see Figure 3b), an infinite set of potential locations for a figure. The ground object THE-MAT fixes the starting point of these vectors, the preposition ABOVE determines their direction.

Each preposition defines a particular type of region, by picking out those vectors from the total vector space that point in a particular direction or have a particular length. Figure 4 illustrates the sets of vectors for *behind*, *near*, and *outside* by shading the areas where the endpoints of these vectors are, with some illustrative vectors. For *behind*, different types of regions are possible, depending on the strictness of the interpretation (a single line, a cone, a half-space). For *near*, the length has to be smaller than a contextually given threshold.

The motivation for using vectors is that modifiers such as *three feet* or *high* can be applied in a more or less intersective way, that is, these modifiers are interpreted as sets of vectors themselves, and intersected with the PP denotation. The PP *three feet above the mat* simply denotes the set of vectors that are both *three feet* in length and pointing upward from the mat. In this way, a compositional interpretation of the structure [$_{PP}$ three feet [$_{PP}$ above the mat]] is possible.



(a) (b)

FIGURE 3 *Vectors for* (the cat is) above the mat

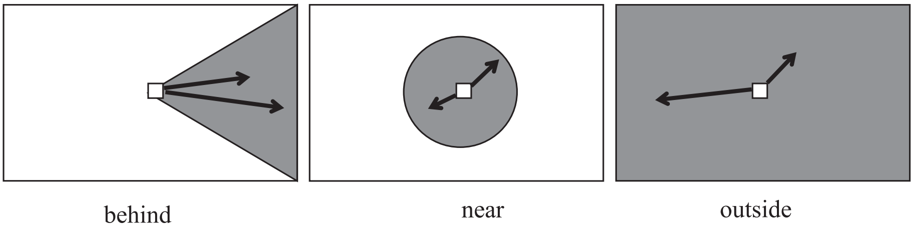


FIGURE 4 *Vector denotations for* behind, near, *and* outside

But the vector-approach has many additional advantages. First of all, the vectors bring along with them an algebra with addition and multiplication. One can take a vector and multiply it by a number >1 to get a longer version and a positive number < 1 to get a shorter version. The denotations of *above* and *outside* are *upward monotone* for every ground: if we lengthen a vector in the denotation of *above* or *outside*, then the result is still *above* or *outside*. However, *near* is not upward monotone. All three prepositions are *downward monotone*: if they apply to a vector, then also to a shortened version of it. Zwarts (1997) and Zwarts and Winter (2000) propose that upward monotonicity is a requirement for measure phrase modification (hence *three feet above*, *three feet outside*, but **three feet near*), and downward monotonicity is a potential universal for all simple prepositions. This approach to spatial denotations took its inspiration from the generalized quantifier theory of determiners (Barwise & Cooper, 1981). The region-based approach might also allow the formulation of such constraints, using the part relation. Most prepositions might be downward monotone, but *on* is definitely not. If a region *a* is in, outside, near, or above *b*, and *c* is a part of *a*, then *c* is in that relation to *b* too. Because of the connection requirement that property does not hold for *on*.

The vector approach has been applied in several detailed semantic and syntactic studies (Bohnemeyer, 2011; Gehrke, 2008; Helmantel, 1998; Mador-Haim & Winter, 2007; Svenonius, 2008; Zwarts, 2003), and it has connections to domains other than space, to conceptual space theory (Gärdenfors, 2000), the semantics of degree adjectives (Faller, 2000; Winter, 2005), force dynamics (Gärdenfors, 2014; Wolff, 2007), and shape-descriptions (Levinson, 1994; Marr, 1982).

Vectors work most naturally with prepositions that describe a relation between two separate objects, and they seem less appropriate for the simple topological prepositions *at*, *in*, and *on*, where the objects are not spatially separate. This might suggest a division of labor between the region-based approach (for the simple topological prepositions *at*, *in*, *on*) and the vector-based approach (for the other prepositions). On the other hand, typical uses of *on* combine a regional component (connection) with a vectorial component (in the upward direction), showing that the two approaches cannot be kept apart. Note that the vectorial prepositions cannot be identified with the projective prepositions, which, according to Herskovits (1986) are the prepositions based on a direction or axis. (These directions can be based on intrinsic properties of the ground, on absolute features of the environment or on the relative position of an observer. These distinctions of frame of reference are more or less independent. See Levinson, 1996 for one overview of this intensively discussed topic.)

As Table 1 shows, the distinction between topological and projective prepositions that Herskovits made has some clear representatives on both ends, but in the middle, there is a fairly large group of

TABLE 1 Classification of locative prepositions

Topological, region-based		Projective, vector-based
at, in, on	between, inside, near, outside	above, behind, below, beside, in front of, left of, next to, over, under

prepositions that are difficult to classify. One reason for this is that there is a gap between the intuitive ways in which a mathematical concept such as ‘topology’ are used (also in Piaget & Inhelder, 1967 and Talmy, 1977) and serious mathematical treatments. Crangle and Suppes (1989) is one of the few papers that discuss the variety of prepositions from the perspective of different geometries.

The typology of locative prepositions is not only related to mathematical distinctions, it is also highly relevant for morphosyntax. The regional or topological prepositions are often smaller and, in languages with case marking, the first to be expressed as cases, and the projective prepositions are often bigger and in many languages derived from nouns. Svenonius (2008) suggests that topological prepositions have a special syntactic component that he calls Axial Part, which is one of the heads in the functional structure of the prepositional phrase.

2.3 | More on paths

The domain of path prepositions has its own distinctions and properties, as we will see, but at the same time, this domain has to be related to the place domain. What makes path prepositions especially complicated is that they also interact with the semantics of verbs. Path concepts that are expressed by prepositions in one language are expressed by verbs in another language (roughly, the so-called satellite-framed or verb-framed distinction of Talmy, 1985). Also, the meaning of verb and PP has to combine in a compositional way to arrive at the path described by the verb phrase as a whole. Because this overview focuses on prepositions, I leave verbs out of consideration, noting only that an important part of what is said about directional prepositions is also relevant for directional verbs in one way or another.

An influential idea in the area of directional prepositions is that their denotation can be given in terms of paths. Following Jackendoff (1983), the notion of path figures in many formal treatments (Cresswell, 1978, Bierwisch, 1988, Eschenbach, Tschander, Habel, & Kulik, 2000, Verkuyl & Zwarts, 1992, Piñon, 1993, Wunderlich, 1993, Nam, 1995, Kracht, 2002, Zwarts, 2005, Gawron, 2006, but see Fong, 1997 for a different approach to directionality, without paths, and Mani & Pustejovsky, 2012 for a wider perspective on motion). I will take the approach of Zwarts (2005), where a path is a directed one-dimensional stretch of space modeled as a continuous function p from the real interval [0,1] to some domain of places (either regions or vectors, I will abstract away from that here).

Note that the path is a purely spatial curve, so that it can be used to represent not only how a figure moves but also how a figure is shaped (Gawron, 2006; Talmy, 1996). Vectors and paths are similar in many respects, but they function differently in the semantics of prepositions. A vector is used to represent one position (relative to a ground), a path is used to represent a sequence of positions.

There is a basic distinction between three types of directional PPs, depending on what part of the path is related to the ground, as shown in Table 2 (with terminology from the domain of spatial cases added for subclasses, Pantcheva, 2010).

Take the PP *onto the mat*, which denotes the set of paths that have their final position on the ground, that is, $p(1) \in \text{ON}(\text{THE-MAT})$. The goal or cofinal operator TO can be defined as a general function from

TABLE 2 Types of directional prepositions

Source (from) prepositions	Route (via) prepositions	Goal (to) prepositions
condition on starting point	condition on all or intermediate points	condition on end point
from, out of, off (coinitial) away from (recessive)	along (prolative) past (transitive) through, over, across, around (mixed)	to, into, onto (cofinal) towards (approximative)

a set of places P to the set of paths that end at those places, that is, TO(P) = { p: p(1) ∈ P }. The source or coinitial operator FROM has 0 instead of 1, which is why source and goal paths can be seen as each other's mathematical reversals, like *onto* and *off*. The route prepositions apply the locative condition either to one intermediate part of the path (*go past the tree*, transitive) or to the whole path (*go along the river*, prolative). Most route prepositions show mixed behavior in this respect (such as *through the woods*). The approximative and recessive are versions of the cofinal and coinitial, respectively, that stop and start at some distance from the ground.

These are the kind of distinctions that play a role in the prepositional domain (Bennett, 1975; Jackendoff, 1983), in spatial case systems (Creissels, 2009; Kracht, 2002), but also for motion verbs (Asher & Sablayrolles, 1995). How directionality is lexically and morphosyntactically encoded in all these domains is a complex issue that involves parametric differences between languages (case vs. preposition, satellite-framed vs. verb-framed) as well as general pragmatic conditions (Lestrade, de Schepper, & Zwarts, 2011; Nikitina, 2008; Zwarts, 2010a). In addition, there are also nonspatial factors that play a role in the expression of motion (Wälchli & Cysouw, 2012).

A typology such as this does not require more than an informal notion of path. However, if we assume that the notion of path is part of a formal algebra, then some new possibilities open up. If we allow for the concatenation of paths, as shown in Figure 5, then it becomes possible to classify the PPs on the basis of the algebraic properties of their denotations. A notion of cumulativity can be defined for directional PPs (closure under concatenation) that is not only conceptually very similar to the notion of cumulativity (unboundedness) for plural and mass nouns and atelic verb phrases (Krifka, 1998) but also that explains why certain prepositions (those not closed under concatenation, that is, noncumulative) lead to telic aspect (*walk to or past the store*), and other prepositions (the cumulative ones) lead to atelic aspect (*walk towards/along the river*). Combining the algebraic properties of cumulativity and reversal also gives a tighter typology of path expressions (Table 3).

Outside the linguistic domain, we can find a variety of models of directionality in geographic information science, working in the spirit of the qualitative region connection calculus that we saw earlier. I just mention one here, and refer to Pustejovsky and Moszkowicz (2011) for a recent overview. The 9-intersection calculus (Mark & Egenhofer, 1994) represents different ways in which a line can intersect a region and can be used in the semantic representation of verbs such as *cross* and *reach* or prepositions such as *through* and *to*. Figure 6 gives an example of one possible relation between a line A and a region B. The matrix represents this relation in terms of intersections between the boundary (∂A), interior (A^0), and exterior (A^-) of the line and the boundary (∂B), interior (B^0), and exterior (B^-) of the region, arriving at $3 \times 3 = 9$ possible intersections. What is characteristic for the situation depicted in Figure 6 is that the interiors of line and region have no overlap with each other ($A^0 \cap B^0 = 0$) or with each other's boundaries ($\partial A \cap B^0 = 0$ and $A^0 \cap \partial B = 0$).

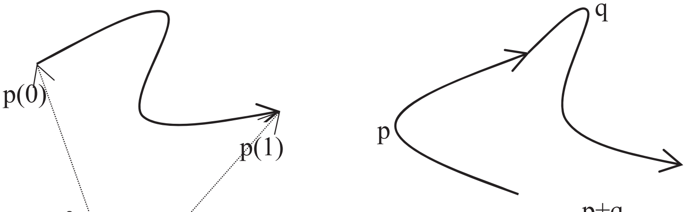


FIGURE 5 A path as a function from [0,1] to positions and concatenation of p and q

TABLE 3 Types of directional prepositions

	Nonreversible	Reversible
Noncumulative (not closed under concatenation)	Transitions (from, to, …)	Cycles (past, through, all the way around)
Cumulative (closed under concatenation)	Progressions (towards, away from)	Continuations (along, through, around and around)

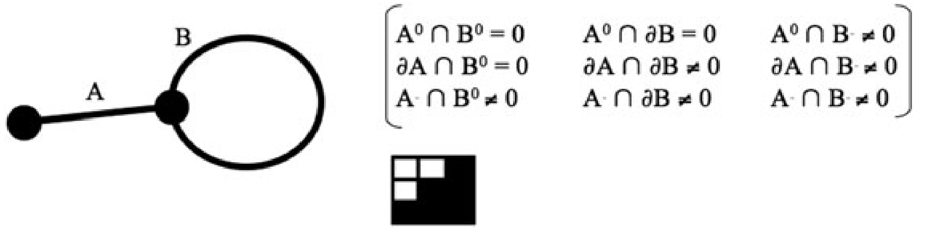


FIGURE 6 A line–region relation in the 9-intersection calculus with corresponding 'bitmap'

3 | COGNITIVE ANTITHESIS: FUNCTION, POLYSEMY, AND RELATIVISM

The picture of spatial semantics painted in the previous section might be associated with a view on spatial language with the following three properties: *geometrical* (with respect to its view of space), *classical* (in its treatment of categorization), and *universalist* (as for its view on language variation). Take the preposition *on* again. A semantic analysis of its meaning is geometrical if it is based exclusively on topology ('connection') or projection ('vertical'), or other geometric notions. It is classical to the extent that the application of *on* to concrete situations in the world is defined in terms of necessary and sufficient features. If it claims that all languages in the world have the same concept as expressed by *on*, then it can be characterized as universalist. There is a relation between these properties. If the geometrical structure of space determines spatial language, then we expect languages to be very similar in this domain. Furthermore, this well-defined mathematical basis would seem to give rise to straightforward classical definitions.

Although this picture is never seriously defended by anybody, as far as I know, it is often taken as a kind of idealized, negative starting point (or straw man, one might even say) for much work on spatial language in the last few decades, especially in the so-called cognitive linguistics framework (Geeraerts & Cuyckens, 2007). There are demonstrations now that geometry is not enough for defining prepositional meanings, but that other factors need to be taken into account too, especially *functional* factors such as support and attachment (Section 3.1). Prepositions have also provided some of the best examples of nonclassical *polysemous* categories, defined in terms of prototypes and family resemblance structures (Section 3.2). Finally, considerable crosslinguistic variation has been found in the domain of space, with potential *relativistic* consequences for the relation between language and thought (Section 3.3).

3.1 | Geometry and function

Many problems for the idea that spatial prepositions are geometrically defined originally come from Herskovits (1986) and Vandeloise (1991). Consider the situations in Figure 7.

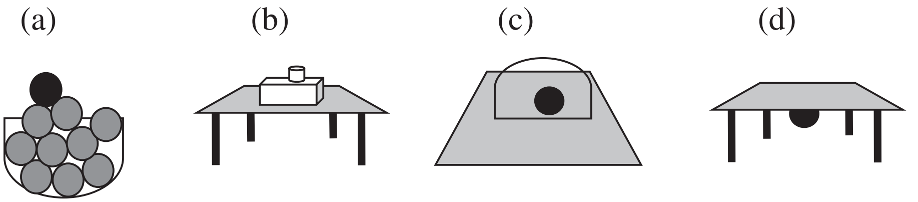


FIGURE 7 The role of function in the (mis)application of in and on

Pictures a and b in Figure 8 give situations in which the geometric conditions for *in* and *on*, respectively, are *not* satisfied (no inclusion and no contact, respectively), but still these prepositions can be applied, as illustrated by example 9a and 9b below. In pictures c and d, the geometric conditions for *in* and *on* do apply, but still sentences such as 9c and 9d below cannot be used.

9.
   a. The apple is in the bowl.
   b. The cup is on the table.
   c. The apple is in the bowl. (cf. The apple is under the bowl.)
   d. The ball is on the table. (cf. The ball is under the table.)

In both cases, the explanation involves nongeometric (more specifically, functional) properties of the figure–ground relation. The bowl is a container, and the table is a supporting surface, and the application of *in* and *on* depends on those functionalities. In Figure 7a, the bowl fulfills its function of 'containment', but not in Figure 7c, when it is upside down. In Figure 7b, the table supports the cup (even though it is not in contact with it) but not the ball in Figure 7d (where the ball only touches the table).

Herskovits concludes that we need to distinguish between a geometrically ideal meaning for prepositions and a number of functional use types that are derived from this ideal. Vandeloise, however, takes a more radical approach, claiming that prepositions are only based on functional relations rather than geometric relations. He has 'accessibility' for *close* or *far*, 'access to perception' for *in front of/behind*, 'potential encounter' for *before* or *after*, 'bearer or burden' for *on* or *under*, 'containment' for *in(side)* or *outside*.

The role of function has also been demonstrated in a lot of experimental work (e.g., Carlson-Radvansky, Covey, & Lattanzi, 1999, Coventry, Prat-Sala, & Richards, 2001, Feist & Gentner, 2003, Coventry & Garrod, 2004, the collection of papers in Carlson & van der Zee, 2004). Feist and Gentner (2003) showed that the choice between *in* and *on* is influenced by the labeling of the ground: when the ground is called *bowl* (a 'container') the proportion of *in* is greater than when it is called *plate* (a 'supporter'). Coventry et al. (2001) and Carlson-Radvansky et al. (1999) demonstrated that function not only plays a role for topological prepositions but also for projective prepositions such as *over* and *above*.

Sometimes, the functional interpretation of a PP can have consequences for the referential and grammatical properties of the nominal (Aguilar & Zwarts, 2010; Carlson & Sussman, 2005):

10.
   a. Ada is in the hospital.
   b. Bob went to prison.

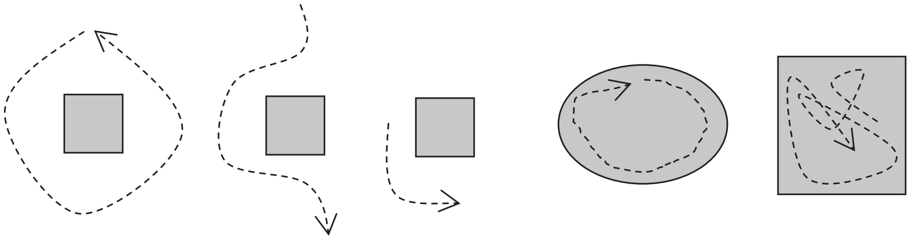


FIGURE 8 *Paths of* around

The definite in 10a does not refer to a uniquely given hospital, but rather to a general institution. This corresponds to a *telic role* (Pustejovsky, 1995) that qualifies the figure as a user of this general institution. As 10b shows, with some nouns the definite article can even be dropped under such interpretations.

The directional layer seems much less affected by function than the locative layer, but the encoding of spatial direction might not be entirely insensitive to non-geometric factors. Lakusta and Landau (2005) show that source and goal paths are not completely asymmetric (and symmetry is what we would expect from their formal path properties in the previous section), but there is a goal bias in the way subjects describe movement situations: the goal is more often encoded in the motion description than the source. This bias might be related to the sequential way in which paths are processed, with the goal (but not the source) being still salient at the end of the path when conclusions about its classification need to be made (Regier, 1996).

3.2 | Classical and prototypical

Spatial prepositions (and closely related adverbs and particles, such as *up*) have played a central role in discussions about polysemy and category structure. Prepositions are typically among the more polysemous items of a language and cognitive linguistics has devoted much attention to the analysis of such prepositions, among which *over* stands out as the most intensively studied one (Brugman, 1981, Lindner, 1983, Lakoff, 1987, Schulze, 1991, 1993, Taylor, 1995, Tyler & Evans, 2003, among many others). Take the preposition *around* (Dewell, 2007; Zwarts, 2004). One dimension of polysemy is presented by the shape of the path and its relation with respect to the ground. The five different paths in Figure 8 correspond to the sentences in 11.

11.

a. She walked around the table.
b. She drove around the pothole.
c. She disappeared around the corner.
d. She ran around the track.
e. She walked around the house.

Around can also be used to describe extension (*a string around a finger*, *people around a piano*), location (*live around the corner*, *somewhere around Chicago*), or rotation (*turn around*). There is no chance that this variety can be captured by one general, classical definition, but there is rather a cluster of senses, with family resemblances (but see Wunderlich, 1993). Lakoff (1987) argues, for the very similarly behaving *over*, that such prepositional clusters can be organized as *radial networks*: there is one central, prototypical meaning, from which other meanings are derived in various ways. The transformations that relate the different senses have a general nature and are shared between different networks. At the same time, the network as a whole still needs to be represented, because the meanings that a preposition has might be motivated, without being fully predictable.

At a different level, prototype effects come back in the structure of the regions that are denoted by prepositions. Psychological experiments (Carlson-Radv+ansky & Irwin, 1993; Hayward & Tarr, 1995; Logan & Sadler, 1996) show that not all spatial positions that fall within a geometrically defined area are equally acceptable for subjects. For a projective preposition such as *above*, for instance, there is a preference for positions that are relatively close to the ground and that do not depart too much from the straight axis. These findings have motivated the use of a spatial *template*, in which different areas of acceptability are directly encoded.

3.3 | Universal and relative

As customary, most of the work on spatial semantics has been done on the basis of English. However, languages differ widely in the ways they talk about space, and what might be true for English might not be true for other languages, let alone for language in general. The idea that there is one universal spatial semantics has been under heavy attack. As always in the universalism or relativism debate, there are two distinct issues, and it is important to keep them apart.

The first issue concerns the question how much variation there really is in spatial language. Although nobody would deny that languages differ in how they describe location and direction, whether they use verbs, nouns, adpositions, or case markers, and how many of them, there are serious differences of opinion about the question whether there are universal constraints on this variation and how these constraints should be represented. On one side of the spectrum are syntactic theories that tend to assume one and the same inventory of functional heads for all languages (contributions in Cinque & Rizzi, 2010), treating crosslinguistic variation as the somewhat more superficial result of different syntactic movement or lexicalization patterns. On the other side, we find typological approaches that see no reason to assume any universal for the domain (Evans & Levinson, 2009:436). It is interesting to contrast in this respect Landau and Jackendoff (1993) with Levinson and Meira (2003). Landau & Jackendoff try to hypothesize universals for spatial prepositions on the basis of an in-depth study of English prepositions (with the observation that English prepositions represent the shape of figure and ground only very schematically). Levinson & Meira, on the other hand, take a bottom up approach, using statistical methods on a small sample of very different languages, in order to find which spatial relations those languages tend to categorize in the same way.

The other side of the relativism debate has to do with a possible Whorfian influence of language on thought. If two languages are different, does that difference cause the speakers of those two languages to think in different ways? Space plays an important role for those who want to answer that question in the positive. One example concerns the difference between English and Korean with respect to object placement. Consider the four situations of object placement and their labelings in English and Korean in Figure 9 (Bowerman & Choi, 2001, 2003).

Although English makes a distinction between 'containment' (*in*) and 'support' (*on*), Korean distinguishes between 'tight' relations (*kkita*) and 'loose' relations (*nehta*, *nohta*). Bowerman & Choi argue on the basis of experimental findings that English speakers have lost the perceptual sensitivity for the tight or loose distinction (that children still have), because their language does not have the distinction.

Another well-known case for Whorfian effects in spatial language comes from the domain of projective relations. Levinson (2003) argues that the predominance of a particular frame of reference (relative versus absolute) has cognitive effects. For example, speakers of a language that uses mostly

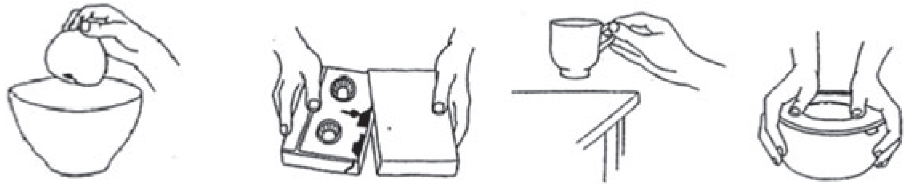


FIGURE 9 Namings of placement in English in Korean

relative frames (e.g., *left*, *right*) remember spatial configurations of objects also on the basis of their own body frame, and speakers of a language with absolute frames (e.g., *east*, *west*) remember the same configurations on the basis of an environmental frame. However, these results have been challenged in Li and Gleitman (2002).

4 | SEMANTIC SYNTHESIS

A geometry-based, classical, universalist approach to spatial semantics is clearly challenged by empirical findings that point to functional factors, family resemblance structures, and extensive language variation. In this final section, I want to consider what might emerge from this fruitful dialectic, by pointing out three important directions for spatial semantics: levels of interpretation, richer ontologies, and higher-order maps.

4.1 | Levels in spatial interpretation

One way to reconcile a geometric semantics with functional and other non-geometric effects is to distinguish different levels of interpretation, in a two-level semantics of prepositions (e.g., Bierwisch, 1996) or even three-level (e.g., Aurnague & Vieu, 1993), or the more standard distinction between (truth-conditional) semantics and (Gricean) pragmatics. Such a distinction has been extremely fruitful in the study of quantifiers (*all*, *some*) and connectives (*and*, *or*), making it possible to combine standard logic with Gricean implicatures (Horn, 1984; Levinson, 2000a), and its potential in the spatial domain has not been sufficiently explored yet (apart from Herskovits, 1986, Levinson, 2000b). Coventry and Garrod (2004) argue that geometric and functional factors both play a role in the interpretation, geometry still being important when the context does not provide enough clues about the function. We therefore want to keep a basic geometrical ‘logic’ but combine it with pragmatic principles. There are two basic types of pragmatic inferences that can both add additional information to a geometric meaning. The first inference (a Q-implicature) can be illustrated on the basis of the preposition *near* (Levinson, 2000b). The fact that this preposition is not applied when the figure is in contact with the ground can be explained from the existence of the contact preposition *on*. These prepositions form a scale (*on*,*near*), with *on* entailing *near*, so that the use of *near* implicates that the figure is not on the ground. The other inference (an I(nformativeness)-implicature) can explain functional and prototypicality effects. A preposition such as *on* will be strengthened to a canonical or stereotypical spatial relation (contact with the upper surface of something instead of just contact), unless there is evidence for the contrary. In this way, a combination of (formal) semantic modeling with (cooperative) pragmatic principles might offer opportunities for explaining how a simple, geometric meaning can be modulated by context and use.

4.2 | Richer spatial ontologies

However, bringing in pragmatic principles into spatial semantics is not enough. It is obvious that figure–ground relations are not exclusively defined in terms of geometry, but that there are also other components, such as ‘containment’ and ‘support’. It seems that force-dynamic notions (Talmy, 1988) play an important role here. If the cup is on the table, then the table causes the cup not to fall. Functional relations such as ‘containment’, ‘support’, and ‘attachment’ all involve forces that the ground exerts on the figure, but working in different spatial directions. When such forces are formalized as vectors (Wolff, 2007), then it becomes possible to enrich spatial relations with located force vectors. The first, informal attempt to do that in Zwarts (2010b) is worked out and formalized in Goldschmidt and Zwarts (2016). Another possibility for enriching spatial ontology can be drawn from Pustejovsky's (1995) dot objects and telic roles. Instead of representing a location (such as a school) only as a spatial location, one can also view it as a *dot object*, a combination of spatial location and the abstract institution. Spatial prepositions can then be made sensitive to such complex ontological types in ways opened up by Pustejovsky's theory.

4.3 | Maps of spatial meaning

The polysemy of prepositions clearly forces us to take a higher-order perspective on their interpretation, as sets of distinct, but related meanings. The role of formal modeling is not to provide us with one classical definition for the prepositional interpretation as a whole, because that is impossible, but rather with defining *types* of spatial situations and how they relate to each other. A preposition can then be interpreted as a *family* of related spatial types.

As Garrod, Ferrier, and Campbell (1999) suggest, it is possible to capture different and troublesome uses of *in* with different types of relations between the figure and ground regions, based on connection (see Section 2.2) and an additional notion of the *convex hull* of a ground region, which is the smallest region of which the ground is a part. In this way, the simple notion of ‘inclusion’ can be replaced by a variety of closely related relations, as shown in 12 and Figure 10.

12.
   a. total topological enclosure: jam in a closed jar, an insect in amber
   b. partial geometric enclosure: a flower in a vase
   c. scattered geometric enclosure: a bird in a tree, an island in an archipelago

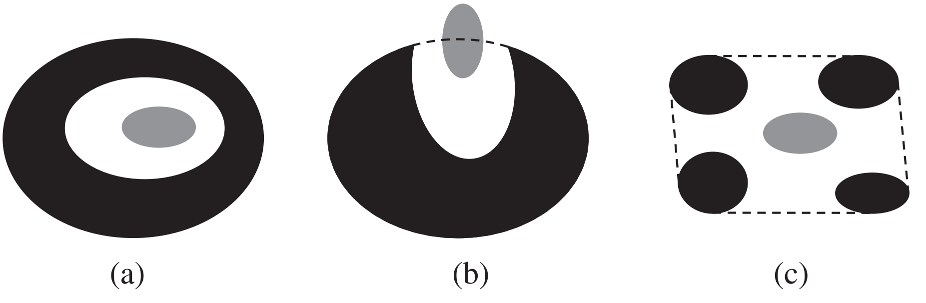


FIGURE 10 *Three types of* in *in RCC*

Each of these different types of *in* can be geometrically defined, even though there is no classical definition that unites them. It is possible to represent different types of spatial relation in a *continuity network* or *conceptual neighborhood graph*, with links connecting the types that are closest to each other.

We can illustrate this with the configurations of the 9-intersection calculus, shown in the conceptual neighborhood graph in Figure 11. Recall from Section 2.3 that each possible line–region relation is represented by a 3 × 3 matrix ('bitmap') that represents which parts of line and region intersect (nonzero, black) and which don't (zero, white). Each possible line–region relation is shown as a node in this graph, with a suggestive picture and the corresponding matrix. The relation that we saw in Figure 6 above is located at the lower right side of Figure 11, surrounded by relations that differ only minimally from it in terms of their intersection properties.

Not only does formal modeling make explicit what types of relations there are, but also it explains how they relate to each other. Mark and Egenhofer (1994) investigated the applicability of linguistic expressions to the different types of intersections and found that subjects had a tendency to use similar labels for coherent areas in the network in Figure 11. The area in the grey box, for instance, contains situations that are labeled with the verb *cross* with relatively more agreement between subjects. In this sense, this conceptual neighborhood graph can be seen as a conceptual similarity space, with spatial terms corresponding to 'convex' regions (Gärdenfors, 2000; Zwarts & Gärdenfors, 2016).

Such an approach also allows for a balanced view of language variation in the spatial domain, in line with the semantic map approach in linguistic typology (Haspelmath, 2003). Languages may differ in the way they divide up a 'space' of meanings. The underlying space may then be assumed to be universal, but there are language-specific 'tesselations' of this space. This is also nicely illustrated with the 'on or in continuum' taken from Bowerman and Choi (2001), shown in Figure 12.

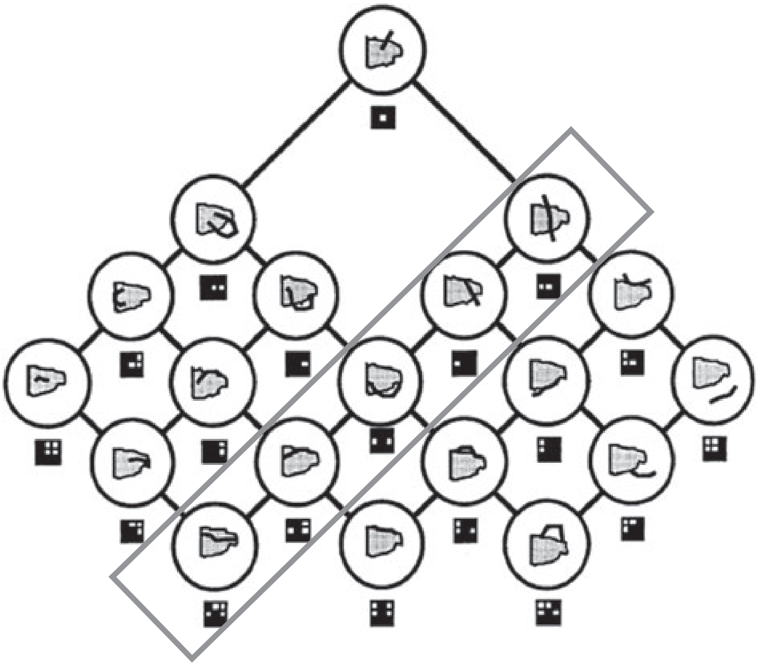


FIGURE 11 Relations between spatial situations in the 9-intersection model (Mark & Egenhofer, 1994)

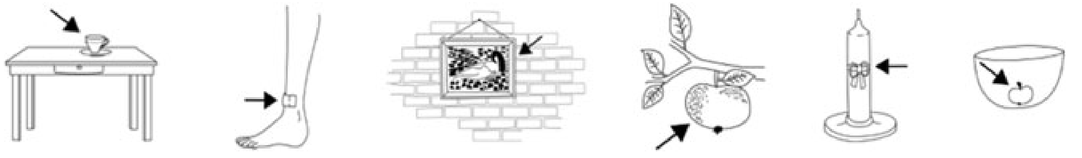


FIGURE 12 The 'on or in continuum' (Bowerman & Choi, 2001)

Using the pictures in Figure 12 and 66 others, Bowerman and Pederson (1992) elicited topological expressions across languages. They found that variation between languages is constrained by a continuum from typical 'on' situations (cup-on-table) to typical 'in' situations (apple-in-bowl). Languages may divide up this continuum in different ways, but always in such a way that each item covers a contiguous part, that is, if an item applies to two pictures on the continuum, then also to a picture in between. Spanish *en* covers all six, English has *in* only for apple-in-bowl, *on* for the other situations, Dutch has *op* for cup-on-table and band-aid-on-leg, *aan* for picture-on-wall and apple-on-branch, *om* for ribbon-on-candle and *in* for apple-in-bowl.

All together, the conclusion of this section is that there does not need to be a fundamental conflict between an approach to spatial semantics that models preposition meanings in terms of geometric concepts on the one hand and the rich empirical data about functional factors in the use of prepositions, their polysemy, and crosslinguistic variation, on the other hand. A greater attention for the role of pragmatic principles, ontologies enriched with forces and functions, and the use of higher-order 'spaces' can help to bring formal theories and empirical data closer together in order to gain a deeper understanding of spatial language.

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