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Topology of Prototypical Spatial Relations Between Lines and Regions in English and Spanish¹

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Abstract

Thirty-two native-speakers of English drew examples of roads that fit the spatial relations to a park, as indicated in 64 English-language sentences. Also, 19 native speakers of Spanish drew examples for 43 Spanish-language sentences. Then, each of the 2856 drawings (2044 English and 812 Spanish) was classified according to the road-park spatial relation into one of 19 categories of spatial relations defined by the 9-intersection model. For each of the 107 sentences, the proportion of subjects drawing each relation was determined. These counts indicate the prototypical spatial relations corresponding to each sentence. Results confirm our previous work on prototypical spatial relations: 2522 of the 2856 drawings (88 percent) fell into just 5 spatial relations, roughly equivalent to 'inside', 'outside' (disjoint), 'enters', 'crosses', and 'goes to'. Evidently, there are many ways in English and Spanish to express relations approximately corresponding to the English inside, outside, enter, cross, and goes-to, and relatively few verbally compact ways to express other spatial relations between roads and parks, perhaps lines and regions in general. The topological results suggest that English and Spanish are very similar in the ways they express road-park spatial relations in English and Spanish. Several Spanish-English pairs of sentences with similar common-sense meanings also had very similar profiles of response across the 19 spatial relation categories. Future work will examine the geometry of the examples drawn by the subjects in this experiment, and will examine other languages.

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Introduction

Spatial relations are a very important aspect of spatial cognition, spatial reasoning, and geographic information systems (Claire and Gupta, 1982; Peuquet, 1986; Abler, 1987; Pullar and Egenhofer, 1988). In a report written in 1991, Egenhofer and Herring (1994) presented the '9-intersection', a new model for characterizing spatial relations between entities in the plane. This model provides a strong formal basis for spatial relations in computational systems, but also represents a hypothesis about spatial relations in cognition and language. We have been using the 9-intersection as a framework for hypotheses, and testing these hypotheses using human subjects. The work so far has concentrated on line-region spatial relations in English, using the example of a 'road' and a 'park' (Mark and Egenhofer, 1992, 1994a, 1994b; Egenhofer and Mark in press). This paper continues that work, reporting results of a new experimental protocol (drawing task), and providing the first systematic comparative results for languages, with parallel experiments in English and Spanish.

The 9-Intersection Model for Spatial Relations

The 9-intersection model (Egenhofer and Herring, 1994) distinguishes the interior, boundary, and exterior of each spatial entity. The spatial relation between two entities is then characterized by a 3 by 3 intersection matrix, that records whether the intersection between each part (interior, boundary, exterior) of one entity and each part of the other entity is empty or not. For a two-dimensional entity (region), the definitions of interior, boundary, and exterior are the intuitive ones; for one-dimensional entities (chains or lines), the boundary consists of the two end nodes, and the interior is every other point on the line (excluding end nodes). The 9-intersection model distinguishes 8 spatial relations between two simple connected regions with no holes, 33 between two unbranched lines, and 19 distinct spatial relations between an unbranched line and a simple region.

Methods

Subjects were presented with outlines of a park, eight to a page, with a sentence describing a spatial relation between a road and a park printed under each. An example is given in Figure 1. Sixty-four sentences were tested in English, and 43 in Spanish. We assembled the sets of test sentences using a variety of techniques. For English, some sentences were group descriptions from a spatial relations grouping task (Mark and Egenhofer, 1994), and others were listed by several native English speakers. Some Spanish-language sentences were elicited from a native speaker of Spanish, and others arose from translation of some of the 64 English-language sentences, again by a native Spanish speaker. Subjects were asked to draw a road on the outline so that it would conform to the spatial relation described in the sentence. In English, the instructions were:

On each of the following 64 diagrams, the shaded polygon represents a state park. Please draw a line on each diagram to represent a road that the spatial relationship to the park that is described by the sentence other the diagram. Try to draw a road that makes the diagram a 'best example' of the relationship described by the sentence. If you think two sentences indicate the same spatial relation, you can drawn the road in the same place to exemplify each.

And in Spanish:

En cada uno de los 43 diagramas, el polígono que está tonado representa un parque. Por favor de dibujar una línea en cada diagrama para representar una carretera que tiene la relación espacial al parque que está descrita en el frase debajo del diagrama. Trata de dibujar una carretera que indica el mejor ejemplo de la relación que la frase describe. Si usted piensa que dos o mas frases indican el mismo relación espacial, puede dibujar la carretera en el mismo lugar para cada diagrama.

Once the drawings were completed, we examined each, and classified the topological spatial relation between each 'road' drawn and the 'park' into one of the 19 spatial relations. We then counted the relative frequency with which each of the 19 relations was drawn, for each of the test sentences across all of the subjects of that language.

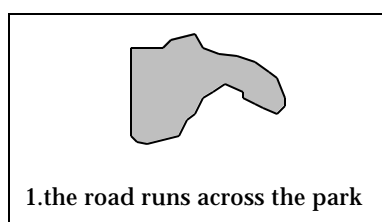


Figure 1. Example of one of the stimuli for the English-language test of production of examples.

Results

Table 1 shows the relative frequencies for each of the 19 relations (plus a category for missing or ambiguous) for each language, totaled across all sentences. We compared the relative frequencies of drawing topologies in Spanish and English by using a Chi-square test. The Chi-square test for non-parametric comparison of relative frequencies in two or more samples requires no category to have an expected value of less than five. In order to achieve this, seven topological categories that were very seldom drawn by these subjects (12, 32, 33, 62, 66, 72, and 76) were combined into a single class 'other'. With a class for cases omitted by subject, the Chi-square table becomes 14 by 2, and there are 13 degrees of freedom. The computed value of Chi-square is 100.12, which with those degrees of freedom is significantly different from zero at the % level. Three topological categories contribute 74 units to this Chi-square value: Classes 13 ('goes to'), 44 ('inside'), and 73 (a special case of 'crosses', truncated at the boundary at one end but extending outside at the other). Drawings of class 13 had a relative frequency almost twice as high for the Spanish sentences as for the English, whereas 'inside' prototypes were more than twice as frequent for the English-language sentence collection. Relation 71 occurred far more often in Spanish. Of course, this may be simply an artifact of the sentence collection, but even that could be interesting. The implication is that there are more ways to talk about 'inside' in English, and more ways to say 'goes exactly up to' in Spanish.







Mathematically, each of the 19 relations is equally unique, and distinct from all the others. Cognitively, however, they are far from equal. More than 85 percent of the drawings (88.6 % for English, 86.6 %) fell into just five of the nineteen topological classes distinguished by the 9-intersection. The drawings

can be considered to be typical or prototypical of the associated spatial relationships. Interestingly, these five most frequently drawn spatial relations are *exactly* the same five relations that were most frequently selected as group prototypes in an open-ended grouping task with road-park drawings (Mark and Egenhofer, 1994b, Figure 11).

TABLE 1: Relative Frequencies of the Spatial Relations for Roads Drawn to Exemplify Locative Sentences, in Descending Order by Total Frequency

		English		Spanish		Total
		Number	%	Number	%	
11		558	27.3	214	26.4	772
75		448	21.9	196	24.1	644
71		430	21.0	156	19.2	586
44		269	13.2	47	5.8	316
13		110	5.4	94	11.6	204
42		70	3.4	28	3.4	98
73		32	1.6	32	3.9	64
46		34	1.7	7	0.9	41
31		33	1.6	7	0.9	40
22		20	1.0	1	0.1	21
74		8	0.4	3	0.4	11
64		6	0.3	3	0.4	9
12, 32, 33, 62, 66, 72, 76		26	1.3	24	3.0	50
Total		2044	100.0	812	100.0	2856

TABLE 2: Prototype = 11 (Outside)

Test sentence	 11	 13	 42	 44	 71	 75	all other
2.05 La carretera pasa cerca del parque	1.000	0.000	0.000	0.000	0.000	0.000	0.000
2.07 La carretera rodea el parque	1.000	0.000	0.000	0.000	0.000	0.000	0.000
2.22 La carretera está fuera del parque	1.000	0.000	0.000	0.000	0.000	0.000	0.000
2.23 La carretera va por fuera del parque	1.000	0.000	0.000	0.000	0.000	0.000	0.000
2.31 La carretera es paralela al parque	1.000	0.000	0.000	0.000	0.000	0.000	0.000
1.13 The road is outside the park	0.969	0.000	0.000	0.000	0.000	0.000	0.031
1.31 The road is entirely outside the park	0.969	0.000	0.000	0.031	0.000	0.000	0.000
1.43 The road encircles the park	0.969	0.000	0.000	0.031	0.000	0.000	0.000
2.33 La carretera está cerca del parque	0.947	0.000	0.000	0.000	0.000	0.000	0.053
1.11 The road ends near the park	0.938	0.031	0.000	0.000	0.000	0.000	0.031
1.38 The road rings the park	0.938	0.000	0.000	0.031	0.000	0.000	0.031
1.39 The road avoids the park	0.938	0.000	0.000	0.000	0.000	0.000	0.062
1.56 The road circles the park	0.938	0.000	0.000	0.063	0.000	0.000	0.000
1.20 The road bypasses the park	0.906	0.000	0.000	0.000	0.063	0.000	0.031
1.37 The road surrounds the park	0.906	0.000	0.000	0.031	0.000	0.000	0.063
1.40 The road goes by the park	0.906	0.000	0.000	0.000	0.031	0.000	0.063
1.47 The road passes the park	0.906	0.000	0.000	0.000	0.000	0.000	0.094
2.06 La carretera pasa lejos del parque	0.895	0.000	0.000	0.000	0.000	0.000	0.105
1.03 The road is near the park	0.875	0.000	0.031	0.000	0.000	0.000	0.094
1.52 The road encloses the park	0.875	0.000	0.000	0.031	0.000	0.000	0.094
1.61 The road starts near the park	0.875	0.031	0.000	0.031	0.031	0.031	0.001
2.08 La carretera bordea el parque	0.842	0.000	0.000	0.000	0.000	0.000	0.158
1.22 The road runs along the park	0.719	0.000	0.000	0.031	0.031	0.000	0.219
1.33 The road runs along the park boundary	0.719	0.000	0.000	0.031	0.000	0.000	0.250
2.32 La carretera pasa por el borde del parque	0.684	0.000	0.000	0.000	0.053	0.000	0.263
1.10 The road runs along the edge of the park	0.594	0.000	0.000	0.031	0.000	0.000	0.375
2.39 La carretera empieza fuera del parque	0.579	0.158	0.000	0.000	0.000	0.263	0.000
1.53 The road starts just outside the park	0.469	0.031	0.000	0.000	0.094	0.406	0.000
1.58 The road goes away from the park	0.469	0.156	0.000	0.000	0.063	0.250	0.062
1.25 The road ends just outside the park	0.438	0.125	0.000	0.000	0.156	0.250	0.031
2.42 La carretera termina nada mas fuera del parque	0.316	0.158	0.000	0.053	0.158	0.211	0.104
2.04 La carretera recorre el parque	0.263	0.000	0.000	0.211	0.158	0.211	0.157

Tables 2-6 include the 107 sentences tested, grouped by the topology most frequently drawn to represent that sentence. Within each table, the sentences

are listed in descending order of the relative frequency of the most typical spatial relation. Relative frequencies for the other prototypical classes are in the columns of each table. (The one sentence dominated by some other spatial relation, a special case of crosses, is included in Table 5.) The first column of each table is a sentence number, beginning with 1 for English and 2 for Spanish.







Outside

Thirty-two sentences (20 English, 12 Spanish; see Table 2) were most frequently illustrated by roads drawn entirely outside (disjoint from) the park. Some Spanish-English pairs of equivalent sentences had remarkably similar frequencies for their most frequent classes (for example, Table 2, sentences 2.32 and 1.10, or sentences 1.25 and 2.42).

Inside

Only 14 sentences (Table 3) had most frequently drawn topologies in which the road was entirely inside the park. Whereas seven English-language sentences were exemplified by drawing roads entirely inside the park by more than 80 percent of the subjects, the highest frequency for drawings inside for any Spanish sentence was 52.6 percent (sentence 2.24).

TABLE 3: Prototype = 44 (Inside)

Test sentence	 11	 13	 42	 44	 71	 75	all other
1.50 The road is inside the park	0.000	0.000	0.000	0.938	0.031	0.000	0.031
1.08 The road is enclosed by the park	0.000	0.000	0.000	0.875	0.031	0.000	0.094
1.24 The road is within the park	0.000	0.000	0.000	0.875	0.000	0.000	0.125
1.06 The road is contained entirely within the park	0.000	0.000	0.094	0.844	0.000	0.000	0.062
1.26 The road starts and ends in the park	0.000	0.000	0.031	0.844	0.000	0.000	0.125
1.29 The park encloses the road	0.000	0.000	0.000	0.844	0.000	0.031	0.125
1.42 The road is in the park	0.000	0.000	0.031	0.844	0.031	0.000	0.094
1.18 The road is entirely contained in the edge of the park	0.000	0.000	0.063	0.531	0.000	0.000	0.406
2.24 La carretera comienza y caba en el parque	0.053	0.000	0.211	0.526	0.000	0.000	0.210
1.16 The road connects portions of the park	0.000	0.000	0.188	0.500	0.063	0.063	0.186
2.36 La carretera está confinada en el parque	0.053	0.000	0.105	0.421	0.053	0.105	0.263
2.20 La carretera está contenida en el parque	0.000	0.000	0.158	0.368	0.211	0.158	0.105
2.28 La carretera está dentro del parque	0.000	0.000	0.263	0.368	0.053	0.158	0.158
2.30 La carretera está en el parque	0.000	0.000	0.053	0.368	0.158	0.000	0.421

Crosses, Enters, Goes To

Twenty-four sentences (Table 4) were illustrated by roads that 'crossed' or otherwise 'bisected' the park. Another very basic type spatial relationship is a

path from the inside to the outside of a container, which we refer to here as 'enters'; this spatial relation was most-frequent for 30 of the sentences (Table 5). Nine others involved roads which had one end on the park boundary but which otherwise were outside the park (see Table 6). In all of these tables, there are pairs of sentences which seem to be direct translations of each other, and for which the frequencies of different topological examples are also about equal. For example, in Table 5, "La carretera va al parque" was exemplified by a 'goes to' relation by 63 % of Spanish-language subjects, while "The road goes to the park" was drawn that way by 62 % of English-language subjects.

TABLE 4: Prototypes = 42,71 (Crosses)







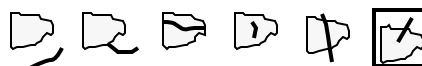






Test sentence							all other
	11	13	42	44	71	75	
1. 57 The road comes through the park	0.000	0.000	0.000	0.000	0.969	0.000	0.031
2. 27 La carretera divide el parque	0.000	0.000	0.053	0.000	0.947	0.000	0.000
1. 48 The road transects the park	0.000	0.000	0.000	0.031	0.938	0.000	0.031
1. 32 The road divides the park	0.000	0.000	0.031	0.000	0.906	0.000	0.063
1. 54 The road crosses the park	0.000	0.000	0.000	0.000	0.906	0.031	0.063
1. 21 The road cuts through the park	0.000	0.000	0.031	0.000	0.875	0.031	0.063
2. 02 La carretera atraviesa el parque	0.000	0.000	0.105	0.000	0.842	0.000	0.053
2. 03 La carretera cruza el parque	0.000	0.000	0.158	0.000	0.842	0.000	0.000
2. 38 La carretera y el parque se cruzan	0.000	0.053	0.000	0.000	0.842	0.053	0.052
1. 12 The road goes through the park	0.000	0.000	0.156	0.000	0.813	0.031	0.000
1. 14 The road splits the park	0.000	0.000	0.094	0.000	0.813	0.031	0.062
1. 17 The road cuts across the park	0.000	0.000	0.094	0.031	0.813	0.000	0.062
1. 30 The road bisects the park	0.000	0.000	0.031	0.000	0.813	0.000	0.156
1. 09 The road cuts the park	0.000	0.000	0.156	0.000	0.781	0.063	0.000
2. 18 La carretera va a través del parque	0.000	0.000	0.105	0.053	0.737	0.000	0.105
1. 27 The road goes across the park	0.000	0.000	0.156	0.125	0.688	0.000	0.031
2. 01 La carretera pasa por el parque	0.211	0.000	0.053	0.000	0.684	0.000	0.052
1. 59 The road traverses the park	0.094	0.000	0.000	0.094	0.656	0.031	0.125
1. 46 The road intersects the park	0.000	0.156	0.000	0.031	0.594	0.094	0.125
1. 41 The road and the park intersect	0.000	0.219	0.000	0.000	0.531	0.156	0.094
1. 01 The road runs across the park	0.000	0.000	0.469	0.000	0.500	0.000	0.031
2. 17 La carretera conecta partes del parque	0.000	0.053	0.105	0.105	0.316	0.158	0.263
2. 25 La carretera termina fuera del parque	0.158	0.053	0.000	0.000	0.316	0.316	0.157
1. 04 The road spans the park	0.125	0.000	0.438	0.125	0.219	0.000	0.093

TABLE 5: Prototype = 75 (Enters)



Test sentence	11	13	42	44	71	75	all other
1.49 The road goes into the park	0.000	0.031	0.000	0.000	0.031	0.906	0.032
1.35 The road comes out of the park	0.000	0.000	0.000	0.000	0.063	0.906	0.031
1.51 The road comes from the park	0.000	0.063	0.000	0.031	0.000	0.906	0.000
2.16 La carretera termina dentro del parque	0.000	0.000	0.000	0.000	0.000	0.895	0.105
1.07 The road ends in the park	0.000	0.031	0.000	0.031	0.000	0.875	0.063
1.28 The road ends just inside the park	0.000	0.000	0.031	0.063	0.031	0.875	0.000
1.36 The road leaves the park	0.000	0.000	0.000	0.000	0.063	0.875	0.062
1.45 The road comes into the park	0.000	0.000	0.000	0.000	0.063	0.875	0.062
1.15 The road exits the park	0.000	0.125	0.000	0.000	0.031	0.781	0.063
1.05 The road enters the park	0.000	0.188	0.000	0.000	0.031	0.750	0.031
2.11 La carretera se pierde en el parque	0.000	0.053	0.000	0.000	0.000	0.737	0.210
1.63 The road starts just inside the park	0.031	0.000	0.000	0.125	0.000	0.719	0.125
1.64 The road runs into the park	0.000	0.063	0.000	0.000	0.188	0.719	0.030
1.34 The road starts in the park	0.000	0.000	0.000	0.219	0.000	0.688	0.093
2.19 La carretera empieža dentro del parque	0.053	0.000	0.053	0.000	0.053	0.684	0.157
2.21 La carretera entra en el parque	0.053	0.000	0.000	0.000	0.263	0.632	0.052
2.34 La carretera sale del parque	0.053	0.211	0.000	0.000	0.053	0.632	0.051
2.41 La carretera viene del parque	0.105	0.211	0.000	0.000	0.000	0.632	0.052
1.02 The road goes out of the park	0.000	0.156	0.031	0.000	0.031	0.625	0.157
2.10 La carretera se aventura en el parque	0.053	0.000	0.000	0.000	0.316	0.579	0.052
1.44 The road starts outside the park	0.281	0.031	0.000	0.000	0.125	0.563	0.000
2.40 La carretera se mete en el parque	0.000	0.105	0.000	0.000	0.316	0.526	0.053
2.12 La carretera muere en el parque	0.053	0.474	0.000	0.000	0.000	0.474	0.000
2.14 La carretera acaba en el parque	0.105	0.368	0.000	0.000	0.000	0.474	0.053
2.09 La carretera se interna en el parque	0.000	0.053	0.053	0.000	0.263	0.421	0.210
2.13 La carretera termina en el parque	0.158	0.368	0.000	0.000	0.000	0.421	0.053
2.35 La carretera deja el parque	0.158	0.211	0.000	0.000	0.105	0.421	0.105
2.37 La carretera empréza en el parque	0.053	0.263	0.000	0.000	0.000	0.421	0.263
1.19 The road ends outside the park	0.344	0.094	0.000	0.000	0.063	0.375	0.124
2.25 La carretera termina fuera del parque	0.158	0.053	0.000	0.000	0.316	0.316	0.157

TABLE 6: Prototype = 13 (Goes to)

Test sentence	 11	 13	 42	 44	 71	 75	all other
2.15 La carretera está conectada al parque	0.053	0.684	0.000	0.000	0.158	0.105	0.000
2.29 La carretera va al parque	0.158	0.632	0.000	0.000	0.000	0.211	0.000
1.23 The road goes to the park	0.000	0.625	0.000	0.000	0.063	0.313	0.000
2.12 La carretera muere en el parque	0.053	0.474	0.000	0.000	0.000	0.474	0.000
2.26 La carretera está conectada con el parque	0.053	0.474	0.000	0.000	0.316	0.158	0.000
1.55 The road ends at the park	0.063	0.469	0.000	0.031	0.000	0.375	0.062
1.60 The road goes up to the park	0.188	0.469	0.031	0.000	0.031	0.188	0.093
2.43 La carretera llega hasta el parque	0.158	0.368	0.000	0.000	0.000	0.263	0.211
1.62 The road is connected to the park	0.000	0.344	0.000	0.031	0.188	0.188	0.249

Summary

As in our previous work, this paper shows that the 9-intersection model provides a good basis for cognitive and linguistic analysis of spatial relations. A small number of line-region spatial relations made up the great majority of drawings produced to exemplify 107 sentences. Over-all frequency of the spatial relations was significantly different for the English and Spanish data. However, similarities are more striking than differences. In quite a few cases, pairs of synonymous Spanish and English sentences appear consecutive, or at least close together, in the summary tables, indicating that their ranges of topological 'meanings' are very similar.

Also of interest is the fact that some natural language road-park sentences show strong agreement in the topology drawn by subjects, and others do not. For 26 of the 107 sentences, more than 90 percent of subjects drew examples with the same topology. It would probably be 'safe' to map these sentences onto particular spatial-relation predicates for database queries or spatial reasoning. On the other hand, there were 20 other sentences for which no single topological pattern was drawn by even 50 percent of subjects. If a user typed or spoke one of these sentences into a natural-language interface for a database or GIS, it might be difficult to satisfy the user's request with a formal query based on the 9-intersection. In some of these sentences, the query might be satisfied by the union of several relations, but others, for example "the road ends outside the park," are ambiguous, since although one end of the road must be outside the park, the sentence does not specify where the other end, or the body of the road, must fall. Also of interest is the fact that the sentences we have tested using an agreement task (Mark and Egenhofer, 1994a, 1994b) all have high consensus in the present study, with 90.6 % of subjects drawing the same topology for 'crosses' and 'goes into', 81.3% for 'goes through', 75 % for 'enters', 68.8 % for 'goes across'. The agreement task might produce results difficult to interpret if applied to sentences with low subject agreement in this drawing task.

In summary, the patterns for responses in Spanish and English show a great deal of similarity, and the results suggest that many spatial relations between roads and parks can be translated between Spanish and English in a fairly direct manner. Since Spanish and English are from quite different branches of the Indo-European languages, this result suggests that natural-language systems for at least the Romance and Germanic languages might be cross-linguistically robust. On the other hand, results suggest that topology based on the 9-intersection model can account for most variation in the meanings of some sentences, but relatively little for others. Whether some of this remaining variation can be accounted for by geometric factors (shapes, lengths, angles) will await further studies.

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