

A formalism for the treatment of polysemy of vertical prepositions in Brazilian Portuguese

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Abstract

In this paper we present a Qualitative Spatial Reasoning formalism for the treatment of the polysemy of the prepositions “sobre” and “sob”. These prepositions are mainly used to express verticality in the Brazilian Portuguese. Through queries in grammars, we established 22 meanings for these prepositions and then we did a Corpus search to see how these prepositions are used in practice. We obtained 384 sentences, which were divided into each of the 22 meanings (called *precisifications*). Finally, we raise six principles that guide the applicability of these prepositions: verticality, visibility, support, salience, proportionality and inclusion and we conclude that the first three principles cited are the most relevant in the use of “sobre” and “sob”.

Introduction

In this paper we present a framework for treat the semantics of spatial prepositions “sobre” and “sob” in Brazilian Portuguese. In order to make the necessary semantic distinctions between different meanings of a word, this framework associates these propositions to a group of synonymous prepositions (like synsets). The prepositions “sobre” and “sob” are associated with different points of view of the same Figure-Ground image schema. This schema is a subtype of frame that seems to be fundamental for cognitive processes, since it deals largely with our physical perceptions. In this sense, prepositions have an important role once their primary meaning is to relate entities in space. Our goal is to show how the semantics of spatial prepositions can be represented in a computationally tractable model, to serve as a reference for communication between humans and machines.

To achieve this aim, we use formalisms of the area of Artificial Intelligence, called Qualitative Spatial Reasoning (QSR) (Ligozat 2013), which formalizes space in terms of elementary entities and primitive relations. Due to the fact that QSR formalizations are more common in English, our aim is to develop a QSR formalization for Brazilian Portuguese. This work uses the Region Connection Calculus (RCC) formalism (Randell, Cui, and Cohn 1992), the formalism presented in (Rodrigues, Santos, and Lopes 2016), and qualitative description of objects given by Abella and

Kender (Abella and Kender 1993) to represent the prepositions in space.

Since this representation deals with the semantic of these terms, we will consequently develop a general theory to approach their *polysemy*. To treat this inherent characteristics of prepositions, our method uses the concepts of Supervaluation Semantics, in order to analyze and describe scenarios unequivocally. Briefly, the *Supervaluation Semantics* make it possible to attribute classical interpretations to a given language by creating multiple versions of itself. These interpretations are called *precisifications*. In this work we model the precisifications according to the qualitative relations defined by the QSR formalisms.

Motivation

The ability to locate objects in the world is one of the most basic skills required by any living organism (Coventry and Garrod 2004). Similarly, being able to describe where objects are located using simple locative terms are considered basic skills for any speaker of a language (Carlson 2000). Spatial expressions are present in our daily life and occur in a wide range of contexts: object location, scene representation, understanding concepts of placing things. The unequivocal formalisation of spatial expressions, however, is certainly a hard, and still open, issue. For example, according to (Taylor 1995), spatial prepositions are among the most difficult terms to acquire in the study of a foreign language. This happens due to the fact that languages differ in the way they map linguistic terms to spatial concepts. Despite this, natural languages encode only a limited number of spatial relations between objects so these have to cover all possibilities.

Literature overview

For a better understanding, we divided the concepts presented in this article into three areas: linguistics, spatial perception and QSR formalisms. In linguistic researches, the semantics of prepositions had long been neglected until the last decades, when the interest for these terms has grown steadily. Several studies (Talmy 1983; Herskovits 1980; 1985; Kreitzer 1997) have convincingly argued that the different uses associated with a preposition are related in systematic ways and also how space is structured according to language. We highlight the work of (Lockwood, Forbus, and

Usher 2005) where is presented a computational model of the use of English spatial prepositions based on the results obtained in (Feist and Gentner 2003), where the authors argue that several factors can influence the description of a scenario involving reference and localized objects. And in (Coventry and Garrod 2004), the author structures the semantics of spatial prepositions through vision, speech and movement. Due to the fact that the works mentioned above were developed for the English language, we only use concepts that are common to both languages. For Brazilian Portuguese, Garcia (2013) based on the cognitive framework of (Tyler and Evans 2003) and (Ilari et al. 2008) argues that prepositional senses can be organized around a small number of primary ones, which are grounded in human spatio-physical experience.

In the area of spatial perception we mention the work of Kelleher and Costello (Kelleher and Costello 2009), that present computational models of the semantics of English spatial prepositions and illustrate how these models can be used in a visually situated dialog system for reference resolution and generation; Casati (Casati and Varzi 1999) investigates the structures of spatial representation; and Abella (Abella and Kender 1993) presents a framework of a system that describes objects in a qualitative way through the choice of a set of prepositions and an appropriate quantification to these prepositions.

And into the area of QSR formalisms, the framework presented here uses the Region Connection Calculus (Randell, Cui, and Cohn 1992), which is a first order theory based on the primitive relation connection; alongside this formalisms we also highlight the Sistla model's (Sistla and Yu 2000), where a set of qualitative relations and rules of reasoning are used to describe topological and directional information.

In addition, we have investigated the use of these prepositions in a corpus of Portuguese language in order to verify how these prepositions are used in spatial descriptions.

Meanings of “sobre” and “sob”

The preposition “sobre”

For the preposition “sobre” we highlight twelve precisifications, in which the Figure uses the Ground as a spatial reference, and we define the meanings in terms of geometrical constraints. We model this by using the RCC-8 relations EQ (equality), DC (disconnection), EC (external connection), TPP (non-tangential proper part), O (overlap), and P (part) plus two primitives: vertical and surface, defined as follows:

1. $\text{vertical}(x, y)$: y -coordinate of every point in x is greater than the y -coordinate of every point in y .
2. $\text{surface}(x)$: this relation represents the surface of object x .

In these two primitives is implicit the concept of *salience*, which according to (Herskovits 1987) we can use a noun that basically denotes an entire object to refer to the region occupied by a typically salient part of it. For example, in the phrase “the cat is on the table”, it may be that the cat's tail is not actually on the table. Similarly, when we say that “the

cat is under the table” we are referring to the surface of the table and not to the legs of the table, so that it is understood that the cat is not actually under the “legs of the table”. Thus, both the function vertical and the function surface consider only the salient part of the objects.

Now, we list the precisifications of the preposition “sobre”¹:

Figure supported by Ground: an object x is supported by another object y if the weight of x presses or pushes y . Usually, the Ground is an outer, horizontal, upward facing surface of the Figure object. There are two cases to consider: the first, when the Figure is directly in *contact* with the Ground, and the second when there is an object located between the Figure and the Ground (*indirect support*).

- (a) $\text{support-EC}(x, y) \equiv_{def} \text{vertical}(x, y) \wedge \text{EC}(x, \text{surface}(y))$.
- (b) $\text{support-DC}(x, y) \equiv_{def} \text{vertical}(x, y) \wedge \exists z[\text{EC}(x, z) \wedge \text{EC}(z, y)]$. ($\text{DC}(x, y)$ is implicit).

The surface of the Figure is not always horizontal, and can only support part of the weight of the Ground object.

- (c) $\text{support-nhs}^2(x, y) \equiv_{def} \neg \text{vertical}(x, y) \wedge \text{EC}(x, \text{surface}(y))$

The Ground may refer to the idea of a geometric line, ie a physical surface not tied to a specific object (eg floor, sea). To represent this line we use the function $\text{line}(x)$.

- (d) $\text{support-line}(x, y) \equiv_{def} \text{line}(y) \wedge \text{vertical}(x, y) \wedge \text{EC}(x, y)$.

Another use for the preposition “sobre” is when the Ground is covered by Figure. The coverage can be partial (when the Ground is partially visible) or total (when the Ground is not visible from any point of view)³.

- (e) $\text{partially-covers}(x, y) \equiv_{def} \text{TPP}(y, x) \wedge \text{P}(\text{surface}(y), \text{surface}(x))$.
- (f) $\text{totally-covers}(x, y) \equiv_{def} \text{TPP}(y, x) \wedge \text{EQ}(\text{surface}(y), \text{surface}(y))$.

Another type of cover occurs when a figure represents a liquid or small particles, thus creating a layer on the bottom. In this case the concept of salience is implicit too. In the phrase “the dust on the book”, the Figure (dust) refers to the set of dust particles. However, in this article, we did not distinguish between these cases and cases of partial coverage.

Figure above the Ground: For the relation above we use a definition of (Abella and Kender 1993): above requires that the projections of bounding boxes on the x -axis (denoted by pbb-x) intersect and that the projections of bounding boxes on the y -axis (denoted by pbb-y) do not intersect.

¹The meanings of the precisifications are based on the work of (Neves 2003; 2000; Castilho 2010; Herskovits 1987; Brenda 2014; Tyler and Evans 2001)

²nhs is the abbreviation for non-horizontal surface

³The definitions of coverage were adapted from the work of (Bennett and Cialone 2014)

- (g) $\text{above}(x, y) \equiv_{def} O(\text{pbb-x}(x), \text{pbb-x}(y)) \wedge \neg O(\text{pbb-y}(x), \text{pbb-y}(y)) \wedge \text{vertical}(x, y)$.

Figure contained in the Ground: The preposition “sobre” can also be used in the sense of inclusion. This occurs when the Ground refers to the idea of container, and Figure is a liquid or a solid that behaves like liquid (eg flour). As an example we have the phrase “o azeite derramado sobre a (dentro da) panela” - “the olive oil poured over the (inside the) pan”. We rely on the concept of open cavity, defined in (Bennett and Cialone 2014), to represent the relation of inclusion.

- (h) $\text{inclusion}(y, x) \equiv_{def} \exists z[\text{has-open-cavity}(x, z) \wedge P(y, z)] \wedge \text{is-liquid}(y)$.

Other spatial uses that do not imply in support:

- **Small surface.** This relation occurs when the Ground is represented by a surface much smaller than the Figure, so that there is no support relationship between the Figure and the Ground, and the Ground is conceptualized as a point in Euclidean space. In this case, the area of the Figure is much larger than the area of Ground, thus there is a disproportionality between the areas. The concept of disproportionality is vague and will not be the subject of a study of this article. Thus, we define the function prop as follows, where φ is a vague threshold:

$$\text{prop}(x, y) \equiv_{def} \frac{\text{area}(x)}{\text{area}(y)} < \varphi.$$

The precisification small-surface defined as follows:

- (i) $\text{small-surface}(x, y) \equiv_{def} \text{EC}(x, y) \wedge \neg \text{prop}(x, y) \wedge \text{vertical}(x, y)$.
- **A-B-C-Trajectory.** When an object, starting from a point A, is thrown over an obstacle B and ends at rest at a point C, describing an arc-shaped trajectory.
 - **Foundation.** In this sense, the preposition “sobre” is used to describe the relation in which the Ground represents entities related to the soil. In this case we do not consider a support relationship, since both the Ground and the Figure are always immobile and the Ground is part of the environment. (mountain, rock, street, for example).
 - Lastly, we have the case where the Ground is a part of the human body.

In the last three cases, we do not define relations in geometric terms, because their interpretations depend more on context than on geometry. Thus, we only name these relations, as follows: (j) ABC-trajectory, (k) foundation and (l) human-body.

In order to verify how the preposition “sobre” is used as a spatial expression, we made a search in the Corpus do Português, and select the 150 most frequently used nouns with this preposition and that denote spatiality. These nouns appeared in 206 phrases. We then classify each of these phrases into one of the twelve precisifications listed above,

and we find the most common synonyms for the preposition “sobre” in each of the precisifications, according to the meaning of each of the 150 nouns. The Table 1 shows the results obtained.

Precisification	Frequency	Substitution
(a)	32.52%	em cima
(b)	2.91%	em cima
(c)	2.43%	em + article
(d)	6.80%	em + article
(e)	10.19%	por cima, em cima
(f)	5.34%	por cima, em cima
(g)	10.68%	em cima, acima
(h)	5.34%	dentro, em + article
(i)	1.94%	em cima, por cima
(j)	4.85%	por cima
(k)	8.25%	em + article
(l)	8.74%	em + article, por + article

Table 1: Uses of preposition “sobre”.

The preposition “sob”

In order to model uses of the preposition “sob” we divide the precisifications of the preposition “sobre” into three groups: (1) partly symmetrical relations: depending on the geometry of the Ground there may be symmetry or not between the two prepositions, ie “sob” may or may not be antonym of “sobre”; (2) symmetrical relations: the relations in this group admit inversion, where “sob” can be used as antonym for “sobre”; (3) asymmetrical relations: there is no possibility of substituting “sobre” for “sob” without prejudice of meaning.

Partly symmetrical relations: the relations defined in (a) and (b) may be extended to the preposition “sob” depending on the geometry of the Ground. For this extension to be admissible, the Ground should not have an area much larger than the Figure area (*proportional area*). Therefore, we can define the following precisifications:

- (m) $\text{support-EC}_i(x, y) \equiv_{def} \text{vertical}(y, x) \wedge \text{EC}(x, \text{surface}(y)) \wedge \text{prop}(x, y)$.
- (n) $\text{support-DC}_i(x, y) \equiv_{def} \text{vertical}(y, x) \wedge \exists z[\text{EC}(x, z) \wedge \text{EC}(z, y)] \wedge \text{prop}(x, y)$. (DC(x, y) is implicit).

Symmetrical relations: The relations defined in the precisifications (e), (f), (g), (i) and (j) are symmetric. If we reverse the position of the Figure and the Ground, “sob” can be used as an antonym of “sobre”. Thus, we define the following precisifications:

- (o) $\text{is-partially-covered}(x, y) \equiv_{def} \text{TPP}(x, y) \wedge P(\text{surface}(x), \text{surface}(y))$
- (p) $\text{is-totally-covered}(x, y) \equiv_{def} \text{TPP}(x, y) \wedge \text{EQ}(\text{surface}(x), \text{surface}(y))$

We divide the relation below (symmetric above) into three precisifications. In the first, the Ground can be affected

by the salience principle, as in the phrase: “o garoto descansou sob a árvore” - “the boy rested under a tree”. (In this example, of course the Ground is just a canopy of the tree). Then we have cases where the Ground is not visible, does not have a support relationship with the Figure and may be contained in an object or environment. Usually, this relation occurs when the Ground is buried, or at the underground location. Thus, we define the following precisifications:

(q) $\text{below}(x, y) \equiv_{def} O(\text{pbb-x}(x), \text{pbb-x}(y)) \wedge \neg O(\text{pbb-y}(x), \text{pbb-y}(y)) \wedge \text{vertical}(y, x)$.

(r) $\text{below-invisible}(x, y) \equiv_{def} \exists z [O(\text{pbb-x}(y), \text{pbb-x}(z)) \wedge \neg O(\text{pbb-y}(y), \text{pbb-y}(z))] \wedge \text{vertical}(y, z) \wedge \text{TPP}(x, z)$.

(s) $\text{below-salience}(x, y) \equiv_{def} O(\text{pbb-x}(x), \text{pbb-x}(y)) \wedge O(\text{pbb-y}(x), \text{pbb-y}(y)) \wedge \neg \text{support}(x, y)$

where $\neg \text{support}$ means that there is no support relation between x and y , as defined in precisifications (m) and (n). Next, we define the symmetric relation to small-surface.

(t) $\text{small-surface}_i(x, y) \equiv_{def} \text{EC}(x, y) \wedge \neg \text{prop}(x, y) \wedge \text{vertical}(y, x)$.

The precisification (u) ABC-trajectory_i is defined similarly to the precisification (j), however the Figure object is thrown under the obstacle B.

Asymmetrical relations: the precisifications (c), (d), (h), (k) and (l) have no correspondence with the preposition “sob”. Thus, in these precisifications, by inverting the order between Figure and Ground, “sob” can not be used to describe such a relation. Finally, we define a precisification that applies only to the preposition “sob”, where the inversion between Figure and Ground does not admit the use of “sobre”. This precisification expresses the relation of “in the midst of” or “inside” For example, in the phrase “os estudantes caminhavam sob a chuva” (“the students walked in the rain”) does not mean that the students are literally under the drops of water, but in the midst of them. Already in the phrase “o mendigo dormiu sob o túnel da Avenida Paulista” (“the beggar slept in the tunnel of Paulista Avenue”) clearly the beggar is not under the tunnel, but inside of him. However, this precisification depends more on the context than on the geometric form of the Ground. Therefore, we will not define a geometric relation, but just name it as (v) in-midst.

As we did with the preposition “sobre”, we searched in the Corpus do Português 150 nouns that accompany the preposition “sob”. We found 178 phrases with these nouns, and classify them among the ten precisifications of “sob”. In addition, for each of these 150 nouns, we investigate which synonyms of “sob” occur more frequently. The result can be seen in Table 2.

Examples

The Table 3 shows an example for each precisification.

Precisification	Frequency	Substitution
(m)	20.79%	embaixo
(n)	2.25%	embaixo
(o)	7.30%	embaixo, debaixo
(p)	17.42%	por baixo, embaixo
(q)	18.54%	embaixo, abaixo
(r)	8.43%	embaixo
(s)	8.99%	embaixo
(t)	2.25%	embaixo
(u)	2.25%	por baixo
(v)	11.80%	por + article, em meio

Table 2: Uses of preposition “sob”.

Discussion

Our research has shown that the use of the prepositions “sobre” and “sob” is based on five main principles: visibility, salience, verticality, support and proportionality. Besides these principles, we can also observe the symmetry between some uses of these prepositions.

“Sobre” is intrinsically linked with visibility: in all 206 sentences obtained in Corpus the figure is visible to the observer of the scene. However, in the precisifications (e) and (f), the Ground’s position is affected by the principle of visibility. For “sob”, the visibility affects the way in which such a preposition is used. Consider the following examples (between parentheses is the precisification to which the example is related):

1. A camisa está sob o casaco - the shirt is under the coat (o).
2. As pedras sob o entulho - the stones under the rubble (p).
3. Os túneis sob os prédios - the tunnels below the buildings (r).

In Example 1 the Figure (shirt) is partially visible whereas in Examples 2 and 3 the Figures (stones, tunnels) are totally invisible. Note that, considering the precisifications affected by visibility, one of every three phrases searched in Corpus is related to this principle. Moreover, in these three examples “sob” is symmetrical to “sobre”, that is, we can use “sobre” by changing the Figure by the Ground: “o casaco está sobre a camisa”, etc.

Another principle that guides the use of the prepositions addressed in this article is verticality. According to the grammar of Portuguese (Neves 2000), the main meanings of both “sobre” and “sob” imply location in upper or lower position. The following examples illustrate the presence of verticality:

4. O pote sobre a mesa - the pot on the table (a).
5. O gato sob a cadeira - the cat under the chair (m).
6. O sofá sobre o piso - the sofa on the floor (d).
7. Os pássaros voam sobre nossas cabeças - birds fly over our heads (g).

In examples 2 to 7 the verticality principle is present, ie the figure is in a higher (4,6,7) or lower (2,3,5) position in relation to the Ground.

Precisification	Example
(a)	O pote sobre a mesa - the pot on the table
(b)	As flores sobre a mesa - flowers on the table (where the flowers are inside a vase)
(c)	O quadro sobre a parede - the picture on the wall
(d)	O sofá sobre o piso - the sofa on the floor
(e)	O paletó sobre a camisa - the jacket over the shirt (the shirt is partially exposed)
(f)	Lençól sobre o colchão - bed sheet on the mattress
(g)	Os pássaros voam sobre nossas cabeças - birds fly over our heads
(h)	Ele derramou água sobre a panela - He poured water on (inside) the pan
(i)	A câmara sobre o tripé - the camera on the tripod
(j)	O jogador chutou a bola sobre o gol - the player kicked the ball over the goal
(k)	A casa sobre a rocha - the house on the rock
(l)	Colocou as mos sobre a cabeça - He laid his hands on his head
(m)	O gato sob a cadeira - the cat under the chair
(n)	Dólares sob o colchão - dollars under the mattress (there is a bed sheet on the mattress)
(o)	A camisa sob o casaco - the shirt under the coat
(p)	As pedras sob o entulho - the stones under the rubble
(q)	A caixa sob a mesa - the box under the table (no contact between box and table)
(r)	Os túneis sob os prédios - the tunnels below the buildings
(s)	O garoto descansou sob a árvore - the boy rested under a tree
(t)	O tripé sob a câmara - the tripod under the camera
(u)	Jogou as chaves sob a porta - He threw the keys under the door
(v)	Caminhava sob a névoa - He walked under (in the midst) the mist

Table 3: Precisifications and examples

Another factor to consider for the applicability of the prepositions in question is the salience, when we use a part of the object to refer to the whole. In example 5 we can observe this principle: the cat is under the seat part of the chair and not under the legs of the chair.

The fourth principle is the support. The support occurs when the weight of the Figure presses or pushes the Ground. This principle is related to gravity, that is, if we remove the Ground, the Figure will suffer the effects of the gravitational force. In example 4, the Figure (pot) presses the Ground (table) against the floor, and in the absence of the table, the pot will fall to the floor.

Finally, we have proportionality. Consider the following scenarios: (i) an elephant climbing on a table; (ii) a cat climbing on the same table. In case (i) it is admissible to say that “the elephant is on the table” and “the table is under the elephant”, whereas in case (ii) we can say that “the cat is on the table”, but it is not correct to say that “the table is under of the cat”. This is due to the ratio between the area of the Figures (cat, elephant) and the Ground (table).

We also highlight another secondary principle that influences the use of “sobre” and “sob”: inclusion. In the following examples we observe the inclusion, respectively, in a container and a environment:

8. Ele derramou a água sobre (dentro da) a panela - He poured water on (inside) the pan (h).
9. Ele caminhava sob (em meio) a névoa - He walked under (in the midst) the mist (v).

In Table 4 we relate the principles discussed above and the precisifications. In the Frequency column we observed the presence of these principles in the 384 phrases analyzed. It is clear that verticality, support and visibility are the most significant factors in the use of the prepositions “sobre” and “sob”. We observe that the salience principle is explicitly expressed only in the precisification (s), but, as said earlier, the salience depends more on the context. Thus, the salience may be implicit in other precisifications. The precisification (l) has very specific use (when the Ground is part of the human body), so we do not relate it to any of the listed principles.

Principle	Precisifications	Frequency
Visibility	e,f,o,p,r	23.30%
Verticality	a,b,d,g,i,j,k,m,n,q,r,s,t,u	66.23%
Salience	s	4.17%
Support	a,b,c,d,i,m,n,t	36.95%
Proportionality	i,t	2.20%
Inclusion	h,v	8.33%
Others	l	4.69%

Table 4: Principles and Precisifications

In the Table 5 we have the correspondences (symmetry) between the precisifications of the two prepositions. Where there is symmetry “sobre” and “sob” are antonyms. In cells that contain the symbol (-) there is no symmetry, that is, in these contexts “sobre” and “sob” are not antonyms.

Conclusion

In this article we study the uses of the prepositions “sobre” and “sob” in Brazilian Portuguese. We model the precisifications through formalisms such as RCC-8 and Bounding

“Sobre”	“Sob”
(a)	(m)
(b)	(n)
(c)	-
(d)	-
(e)	(o)
(f)	(p)
(g)	(q),(r),(s)
(h)	-
(i)	(t)
(j)	(u)
(k)	-
(l)	-
-	(v)

Table 5: Symmetry between the prepositions

Boxes, as well as concepts such as cavity and proportionality. We also highlight six factors that work in the use of these prepositions: visibility, verticality, support, salience, inclusion and proportionality.

We did a research in Corpus with texts taken from blogs, obtaining 300 nouns (150 for each preposition) and 384 phrases (206 for “sobre” and 178 for “sob”), in order to verify how the applicability of such prepositions occurs. In addition, we check which are the most commonly used synonyms for “sobre” and “sob” in each of the precisifications.

The research has shown that expressions such as “em-baixo”, “abaixo”, “debaixo”, “por baixo”, “em cima”, “por cima”, “acima” are widely used in the contexts covered in this article. Thus, as future work we intend to use this work to model the polysemy of such expressions, in addition to conducting a research with people, where we will propose a scenario and they should describe it using these expressions. With this, in addition to research in Corpus, we believe that we come very close to how these expressions are used in practice.

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