Utrecht University

Semantic Treatment of Locative Prepositions

Author:
Artuur Leeuwenberg

First Supervisor
Dr. Yoad Winter

Second Supervisor
Dr. Joost Zwarts

A thesis submitted in partial fulfillment for the degree of Bachelor of Science

July 23, 2013

CONTENTS

1. INTRODUCTION

In the broad research area of Artificial Intelligence one of the subjects is natural language semantics. Natural language semantics is about formalizing the meaning of language to a (computer) model. This thesis will be about a small portion of such formalization. It will look at the formal treatment of spatial expressions, in particular the interpretation of locative prepositions (LPs).

First it looks at some issues concerning spatial representation from a more philosophical view. Second, it sets out some of the issues involved in the formal treatment of locative prepositional phrases. At last it will further examine a model for the treatment of LPs proposed by Zwarts and Winter (2000) including the extension proposed by Mador-Haim and Winter (2012), for the treatment of LPs that range not only over definites but also over indefinites.

The goal of this thesis is to give insight in the treatment of LPs from different perspectives and the issues that arise in this research area.

2. PHILOPHICAL ISSUES IN SPATIAL REPRESENTATION

A philosophical introduction to spatial representation of objects and parthood relations.

To build a language model on spatial utterances a clear ontology of space is required. However this appears to be a difficult task. What kind of spatial structure do you choose? What are your spatial entities? and what kind of relations are there between such spatial entities?

In Casati and Varzi (1999) some fundamental properties of objects are mentioned. The first is *wholeness*. Objects can be solid, like a table. Also they can also be scattered, like a broken glass over the floor, which is still referred to as a broken glass, and not just glass, or a lot of glass individual glass pieces.

A second property of objects is that they can be hierarchically structured. A house has a door and a kitchen. The kitchen has a table in it consisting of four feet and a top, and so on.

A third slightly related property is that objects are made of matter. For example, a chair can be made of wood. When you burned the chair, it cannot be that the wood of the chair is still there. For these last two the *parthood relation* is very crucial. First we take a look at the wholeness property of an object, and then we look more carefully at some properties of the parthood relation.

2.1 Wholeness

A theory by Husserl (Husserl (1970) in Casati and Varzi (1999)) is regarded the first thorough formulation of a theory of parts and wholes. He introduces some mereological properties of 'whole' objects. One property is called *causally unitary*, which means that operations performed on certain parts have systematic effects on other parts (say, pulling on one ring of a metal chain results in pulling many others). A different property is *teleologically unarity*; the sharing of a common goal determines a corresponding form of individual integrity (a team of people).

A different approach is to try to define wholeness by means of connectedness. Two ways to do this are that of Whitehead (1920) in Casati and Varzi (1999) and that of Laguna (1922) in Casati and Varzi (1999). Whitehead's approach is explained by means of a brick. What is the difference between a normal brick and a brick that is splitted into two halves? The whole brick is connected and the broken brick is not. Whitehead explains the notion of connectedness in (1).

(1) x is connected with y iff there exists some z that overlaps both x and y, and that has no part that overlaps neither x nor y.

At first, this seems like a correct explanation of connectedness. However it doesn't hold when z itself is not connected. This means there should also be a restriction on z, namely that it is connected. The result would be a regressive definition of connectedness. This is not very plausible.

The second approach is that of Laguna. He thought of connectedness not as overlap but as 'external contact' of regions. His definition of connectedness is (2).

(2) x is connected to y iff region x and region y have at least one point in common.

This might seem as overlap but it is not. Since points are not regions, sharing of a point does not imply overlap. By means of this definition wholeness can be described as 'self- connectedness' as in (3).

(3) x is self-connected iff any two regions that make up x are connected to each other.
Where two regions a and b make up x iff a is a part of x and b is a part of x and there is no region c that is a part of x and not a part of the union of a and b.

Now this seems a legitimate description. There are some assumptions to be made though. Namely that our variables (x,y and so on) range over spatial or spatiotemporal regions (spatiotemporal regions are spatial regions that carry a time parameter, to indicate change in time).

Still, this does not solve the problem of the broken glass. The broken glass is namely, in the real world, not actually a whole. Although it can be a concept in the cognitive model. For this reason Casati and Varzi (1999) proposed that wholeness in language and human cognition cannot be characterised only on the basis of mereological properties.

2.2 Parthood

Now that we have some idea of the difficulties of wholeness we look at a different, although slightly related, aspect namely parthood relations. The parthood relation is important when thinking about spatial entities and relations. For example, we say that the feet of a table are part of the table. Also we say things like, the begin of the flight was the most exciting part.

Since we reason and speak about the structure of objects and places you want this structure to be part of your theory.

In Casati and Varzi (1999) a discrimination is made between a broad interpretation of 'part' and a narrow relation of 'part'. This comes from the fact that in some cases the parthood relation is transitive, but in some cases it is not. Parthood in the broad sense is necessarily transitive. Parthood in the narrow sense is not. If one particular foot is part of a set of feet and the set of fee are part of the table, then also the particular foot is a part of the table. This would be parthood in the broad sense. narrow parthood comes with a modifier, in Casati and Varzi (1999) it is called ϕ. Some examples of such ϕs would be the modifiers small, large, functional, important. An example of a narrow parthood with as modifier functional is given in (4).

(4) A handle is a functional part of a door and a door is a functional part of a house. $\nRightarrow$ A handle is a functional part of a house.

The modifier limits the normal parthood relation to only those elements that are functional parts of a door. As you can see in (4) those narrow parthood do not always seem to be transitive.

A reaction to this theory is given by Winston, Chaffin and Herrman (1987) in Johansson (2004). They argue that all ϕ categories are transitive, in contrast to what Casati and Varzi (1999) concludes. According to Chaffin and Herrman the intransitivity in the example (4) is actually a mismatch of two types of parthood relations, with different ϕs. They defined six types of parthood relations (or ϕs).

(5) to be a component of an integral object
(6) to be a member of a collection
(7) to be a portion of a mass
(8) to be a stuff of an object
(9) to be a feature of an activity
(10) to be a place within an area

Each of these individual relations is, according to them, transitive. However when mixed together they not need to be transitive at all. Johansson (2004) added to this the fact that parthood expressions are ambiguous. They can be interpreted *directly* or *indirectly.* The direct interpretation of a parthood relation is the strict interpretation (normal interpretation). An indirect interpretation allows you to interpret the relation as if it were transitive. A direct interpretation of a parthood relation does not have to be transitive, although it can be. When following the six types of parthood relations as given above the intransitivity in (4) would by interpreted (directly) as in (11).

(11) The fact that a handle is a DIRECT *component-part-of-the-integral-object* a door, and the door can be a DIRECT *component-part-of-the-*

integral- object a house, but yet the handle does not need to be a DIRECT *component-part-of-the-integral-object* a house.

The theory also allows you to interpret the sentence more loosely (indirect). In this case the transitivity still holds.

3. LOCATIVE EXPRESSIONS

An introduction to locative expressions and some issues in the research area.

Now that we have some general idea of the problems with spatial representation of objects and the properties of parthood relations, we look first, at what locative expressions look like. Furthermore we look at some of the ideas that are formed about these empirical phenomena to get a better understanding of the current theories, for later comparison to Mador-Haim and Winter (2012) and Zwarts and Winter (2000)

3.1 Locative Prepositional Phrases

Locative prepositional phrases (locative PPs) are prepositional phrases that describe a location. They usually have a form similar to (12).

(12) The man is inside the house.

Where The man is called the *located object*, inside is an LP and the house is called the *reference object*. The function of locative PP can differ a lot. Locative PPs can be predicates, arguments and adjuncts (Bierwisch (1988) In Kracht et al. (2002)). Some examples of such are shown in (2)–(4).

(13)	Alfred is *at the school*.	(predicate)
(14)	The letter is lying *on the table*.	(argument)
(15)	I am buying the book *in Berlin*.	(adjunct)

There are very different ways to analyze locative PPs. In Kracht et al. (2002) locative expressions are assigned two layers; one for the *configuration* and one for the *mode*. The *configuration* describes the way in which several objects are positioned with respect to each other. These configurations can be related with prepositions that do not indicate a change of location. Examples could be: at, in, on, between etc. The *mode* describes how the located object moves with respect to the configuration. In Kracht et al. (2002) five modes are mentioned. The mode can be *static*, where the located object does not move with respect to the configuration, *cofinal*, *coinitial*, *transitory* or *approximative*. The last four modes all indicate a specific manner in which the located object moves with respect to the configuration. This corresponds to the discrimination that is made concerning spatial prepositions in Zwarts and Winter (2000). They split spatial prepositions into two categories: *locative prepositions* and *directional prepositions*. Locative prepositions (LPs) are prepositions that introduce, as the name suggest, locations in a static manner (do not imply movement). Some examples are: behind, above and near. Directional prepositions also introduce locations, but they are also dynamic, as they introduce some form of movement or change of location, for example: to, from, around. Directional prepositions often resist predicative constructions, contrary to LPs. An example of this is given in (16), where the directional preposition to is fitted into a sentence with a non-dynamic verb resulting in an incorrect sentence (indicated with a *).

(16) *John is to the park.

3.2 Orientation of Locative Prepositional Phrases

The focus of this thesis is on LPs. In Kracht et al. (2002) the corresponding mode of locative expressions would be the static one.

A characteristic of most locative PPs is that they introduce a located object. Sometimes when a new object or entity is introduced by means of a PP ambiguity arises, as in (17). This is not always the case with locative PPs (Creary et al. (1989) in Kracht et al. (2002)).

(17) Tina didn't drink because of her husband
(18) Tina didn't work in New York

As you can see in (17) ambiguity is introduced as the PP is attached. The first reading of (17) is that Tina didn't drink. Her reason for not drinking is her husband. In the second reading, Tina did drink. Her reason for drinking just wasn't her husband. This ambiguity is a result of the argument-orientation of the PP because of her husband. For the first reading it takes Tina didn't drink as its argument. In the second reading it takes drink as its argument. However in (18), with the locative PP in New York, this does not cause ambiguity.

There are also cases where ambiguity occurs with a locative PP. As you can see in (19), the locative PP can be oriented towards the subject (John is in the garden) alone, but also towards the object (Mary is in the garden) of the sentence.

(19) John sees Mary in the garden.

In Nam (1997) a framework is constructed that deals with this argument-orientation. He discriminates four classes of locative PPs that are similar to the modes in Kracht et al. (2002). For the purpose of this thesis we will only discuss, what Nam calls, *Stative Locatives*. These are similar to Kracht's (2002) static mode and the LPs of Zwarts and Winter (2000). In Nam (1997) rules are constructed to determine the orientation of the locative PP when combined with a transitive verb. For stative locatives the following rule is applicable, see (20).

(20) If a transitive verb can combine with a non-stative locative, then stative locatives are object-oriented with that verb (that is, either object-oriented or construed with both the subject and the object)

In the case of sentence (19), sees is the transitive verb. Since sees can be combined with a non-stative locative (like from in (21)), stative locatives (like in in (19)) are either object oriented (Mary is in the garden) or construed with both the subject and the object (The sentence can be interpreted as John is in the garden, or as Mary is in the garden).

(21) John sees Mary from the garden

3.3 Interpretation of Locative Expressions

Besides this argument orientation, Nam has also constructed a semantic system to interpret LPs. He built a logic of space based on the primitive notion of *region*, the *nearer*-relation, the *between*-relation and a part-to-whole relation $\subseteq$. He also introduced *paths*, which are ordered lists of regions, and *orientations*, which are paths that have an origin from which they start. Locative PPs are interpreted as paths or orientations. For the interpretation of stative locatives the following semantic rule (rule-2 in Nam (1995)) is constructed:
for s, a one-place stative verb (say, sees Mary), and f an extensional locative modifier (say, in the garden), interpret VP $s + f$ by:

(22) $f(s)(x)$ iff $s(x)$ and $\text{INTERSECT}(r(x), \rho f)$

where $r(x)$ denotes the region x occupies and ρf is an orientation or a region (in this case a region) determined by f.

In (21) the locative PP in the garden would modify the stative verb sees Mary to a function that returns true, iff John is in the set of sees Mary and the region of John intersects with the region of in the garden.

Nam's theory works well for locative PPs that are constructed from definite NP's, however it does not tell us how to deal with locative PPs that are constructed by means of an indefinite NP (say, a garden). A theory that does deal with theses indefinites is described in Mador-Haim and Winter (2012). In this thesis this theory will be elaborated.

4. A MODEL FOR THE SEMANTICS OF LOCATIVE PREPOSITIONS

An explanation of how the semantics of LPs are to be interpreted according to the model discussed in Mador-Haim and Winter (2012), that is based on Zwarts and Winter (2000).

LPs can be divided into two types: *projective* LPs and *non-projective* LPs. Projective LPs are differentiated by the fact that their meaning is not merely dependent on the location of its two arguments. To know the meaning of Jim is behind the tower you also need some information about the viewpoint of the speaker. The meaning of non-projective LPs is fully dependent of the locations of its two arguments . The meaning of Jim is inside the tower can be completely determined by the location of Jim and the location of the tower.

In this thesis we will only look at how the system described by Mador-Haim and Winter (2012) and Zwarts and Winter (2000) deals with the semantic interpretation of non-projective LPs. The system is build upon the Montague semantics framework. In this way it has a firm way to deal with compositionality and syntax.

To deal with the spatial aspects of the LPs an ontology of space is introduced. The basic elements of this ontology are *points* and *regions*. As we saw in §3.3, this differs from the model of Nam (1995). Nam uses regions as basic elements. This is an important difference. Since in Mador-Haim and Winter (2012) it is also possible to express mereological properties (like the size or the scatteredness) of regions. Besides the semantic model a spatial model is attached. This spatial model keeps track of the regions that entities, from the semantic model, occupy. The definition of such spatial model is (23).

(23) *Let $\mathcal{M}$ be a topological space. Elements of $\mathcal{M}$ are referred to as points. Subsets of $\mathcal{M}$ are referred to as regions.*

Within this ontology of space the *distance* between points is the euclidian distance (*dist*).There is also a notion of *distance* for regions (DIST). The distance between two non-empty closed regions A and B that are a subset of M and are mutually disjoint is defined as follows:

(24) $\text{DIST}(\text{A,B}) = min(\{dist(x,y)|x \in \text{A} \ \ and \ \ y \in \text{B}\})$

In a more informal way, the distance between region A and region B (that are not empty or scattered into multiple area's) is the length of the shortest line between the two regions. This notion of distance between regions will be important when interpreting LPs. This will be elaborated more later on in §4.2.

4.1 Eigenspace of Entities and Properties

Now that we have some ontology of space, the connection with the semantic model is introduced. In Mador-Haim and Winter (2012) and Zwarts and Winter (2000) there is a clear discrimination between the treatment of definites and indefinites both in the semantic model as in the topologic model. In the semantic model, definites are treated as entities, which is common. However indefinites are treated as predicates rather than entities. An indefinite a car will be interpreted as the predicate CAR (CAR would be the interpretation of car). In other words, it will be interpreted as the set of entities for which the predicate CAR is true.

To link these interpretations in the semantic model to an interpretation in the topological model the notion of *eigenspace* is introduced. For singular entities this is done in (25). Although Mador-Haim and Winter (2012) offer a method to deal with plural entities we will not discuss this.

(25) *The eigenspace of an entity e refers to the region the entity fills in some spatial domain.*

Furthermore every entity in the domain should be assigned an eigenspace. Definites, that refer to entities, can now be interpreted in a spatial way.

Indefinites like a house and London are less straight forward. In Mador-Haim and Winter (2012) they are interpreted as predicates/properties. The indefinite a house would now refer to the set of entities that have the property house. There should also be a way to assign predicates an eigenspace. The way this is done in Mador-Haim and Winter (2012) is by means of the *Property-Eigenspace Hypotheses* (PEH), this is shown in (26).

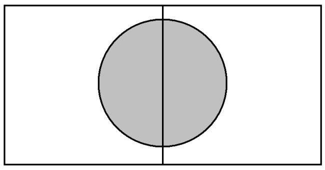
(26) *The eigenspace of a property $\mathcal{P}$ is the union of the eigenspaces of entities in $\mathcal{P}$'s extension.*

More informal, this means that the eigenspace of a property is the union of the eigenspaces of the entities that are in that property. The eigenspace of a car would be the region consisting of all car-regions in the model.

A problem that occurs when interpreting an indefinite like a house by means of the PEH is that there is some form of information loss. When the eigenspaces are united to one big region, it is hard to determine what the eigenspaces are of the individual houses. As shown in §2.1 and supported by Casati and Varzi (1999) it is very hard to separate wholes on the basis of merely mereological information. The resulting region of houses can be scattered (the houses are not next to each other), but also closed (in the case of townhomes). In Mador-Haim and Winter (2012) a clear example is given of when this gives a problem with respect to the interpretation of LPs. Say we have two squares on a paper and one circle, then (27) is true in all cases where the circle is in one of the two squares.

(27) The circle is in a square.

However if the two squares are exactly next to each other and the circle is in the middle (overlapping both squares, as in (28)) the sentence is also true, according to the PEH.



(28)

The circle region is namely inside the union of the two square regions. Although intuitively you would not say that the circle is inside a square if it is not completely inside one of the two squares. This phenomena remains a problem to be solved, also in Mador-Haim and Winter (2012).

4.2 Locative Prepositions as Relations Between Eigenspaces

Since we now have a way to interpret definite and indefinites, LPs can be modelled. LPs are modelled as binary relations between eigenspaces (regions). This can be illustrated best by means of an example. A simple LP is inside. This can be modelled as the subset relation, as you can see in (29).

(29) $\text{INSIDE}(A,B) \Leftrightarrow A \subseteq B$

This would mean that for the sentence (30), the eigenspace of John should be a subset of the eigenspace of the garden for the sentence to be true. As we saw in §2.2 the words in and inside can also be used to express parthood relations. The interpretation of inside in (29) fits very well with the spatial category of parthood of Winston, Chaffin and Herrman (1987) in Johansson (2004) shown in §2.2, in (10). They explained it as 'to be a place within an area'.

(30) John is inside the garden.

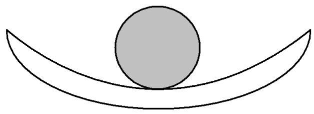
Also the outside relation can be modelled with merely the intersection $\cap$ and the empty set $\varnothing$. It would look like (31).

(31) OUTSIDE(A,B) $\Leftrightarrow$ A $\cap$ B = $\varnothing$

These functions however do not seem to capture the entire use of the LPs inside and outside. If you look at sentence (32), the eigenspace of ball does not necessarily have to be a subset of the eigenspace of bowl.

(32) The ball is inside the bowl.

Still it is common to use the word inside as an LP in situations similar to the one shown in (33).



(33)

It could also be that the use of inside in such situations is not merely locative, but also functional. For example that the fact that, if you lift the bowl you also lift the ball, also has a role in the meaning of inside.

Furthermore it is not fully clear in Mador-Haim and Winter (2012) how eigenspaces should be assigned to entities. It could be the case that we don't think of the eigenspace of an object as its bare volume, but also a part of the surroundings of the object. You can be inside the garden without actually intersecting with any object, meaning that the 'empty' air is maybe also part of the eigenspace of the garden. The observation (33) is also discussed by Zwarts and Winter (2000). They speculate that counter-examples like these should be handled by a general theory of functional cognition and is not per se a problem of linguistic semantics.

There are also LPs that require more complex function to express their meaning. There are some examples in table (37). The use of the DIST-function is also more clear there. Some functions also need the use of a *measuring phrase*. For example: at most 20km, or the more vague notion far.

(34) *A measure phrase denotes a subset of the non-negative real numbers* $\boldsymbol{R}^+$.

This number stands for the normalized (for different types of measuring units; km, mile etc.) distance represented by the measuring phrase. In (35) some examples of measuring phrases, as they are defined in Mador-Haim and Winter (2012) are given.

(35)

20KM= $\{20\}$
AT_MOST_20KM= $\{r : r \leq 20\}$
LESS_THAN_20KM= $\{r : r < 20\}$
AT_LEAST_20KM= $\{r : r \geq 20\}$
MORE_THAN_20KM= $\{r : r > 20\}$

There are two ways to merge an LP and a measuring phrase. The first way is to model the measuring phrase as a function and the second is to model the LP as a function, taking the measuring phrase as an argument. In Mador-Haim and Winter (2012) the second option is assumed. The result is called a *measure-based spatial relation.* The generalized form is given in (36).

(36) *Let $\mathcal{MP} \subseteq \boldsymbol{R}^{+}$ be a set of non-negative real numbers. For any two non-empty closed regions $\mathcal{A}, \mathcal{B} \subseteq \mathcal{MP}$ that are mutually disjoint, the spatial relation* MP_FROM is defined by:

$$\text{MP\_ FROM}(\text{A,B}) \Leftrightarrow \text{DIST}(\text{A,B}) \in \text{MP}$$

(37)

Relation	Definition
far from	$\text{FAR\_FROM}(\text{A,B}) \Leftrightarrow \text{DIST}(\text{A,B}) > c$
close to	$\text{CLOSE\_TO}(\text{A,B}) \Leftrightarrow \text{DIST}(\text{A,B}) < c$

4.3 Properties of Spatial Relations

There are several properties that can be assigned to the different spatial relations. The most important property in this thesis is 'additivity'. To understand the importance of this property it is crucial to know that indefinites can be interpreted in two ways. Either they are interpreted *universally*, or they are interpreted *existentially.* If an indefinite or property is interpreted universally by a relation, the relation holds for every element of the indefinite or property. If an indefinite is interpreted existentially the relation only has to hold for one element of the relation. The way indefinites are interpreted is dependent on the relation. Now that we know this discrimination we look at additivity.

Additivity & anti-additivity Additivity and anti-additivity are defined as follows:
Let R be a relation between subsets of a domain M, and let A, B_1 and B_2 be arbitrary subsets of M. Then relation R is additive in its right argument when the following definition holds.

(38) $R(A, B_1 \cup B_2) \Leftrightarrow R(A, B_1) \vee R(A, B_2)$

Relation R is anti-additive in it's right argument when:

(39) $R(A, B_1 \cup B_2) \Leftrightarrow R(A, B_1) \wedge R(A, B_2)$

For now the notions 'additive' and 'anti'-additive will be used as a reference to additivity and anti-additivity in the relation's right argument respectively.

An example of an anti-additive relation is far from. This is because of the fact that (40) holds for every two regions.

(40) The U.S. is far from Europe ⇔ The U.S. is far from France and far from the rest of Europe.

A relation that is presumably additive is the close to relation. The way it is modelled in (37) it is additive. However in Mador-Haim and Winter (2012) some remarks are made about this additivity. The remarks are about the case when in (41) A is also inside B.

(41) A is close to B

In Mador-Haim and Winter (2012) such phrases are presumed to be false. They presuppose that you cannot say that two object are close to each other if one of them is inside the other. For this particular case an *'outside' presupposition* is introduced. The 'outside' presupposition says to interpret the close to relation as a conjunction of the 'old' CLOSE_TO relation and the OUTSIDE relation. In order to be close to something, you cannot be inside it. For now we will not assume the 'outside' presupposition.

A more important aspect of additivity is that it determines whether an indefinite reference object can be interpreted universally or existentially. It appears to be the case that additive relations, when applied to an indefinite, can be interpreted extistentially and anti-additive relations universally. An example of the additive relation CLOSE_TO is shown in (42).

(42) John is close to a house. ⇔
$\exists x$: house(x) $\wedge$ CLOSE_TO(JOHN, x)

The CLOSE_TO relation takes the eigenspace of john as its first argument, and the eigenspace of the property house, the union of eigenspaces of each element, as its second argument. The entailment in (43) is true because of the additivity of the relation. Since there is an x in house, that has an eigenspace for which the relation holds, it also holds for every property that contains x . In those cases CLOSE_TO (JOHN,x) is part of the disjunction on the right hand side of (37).

(43) John is close to a house. ⇐
$\exists x$: house(x) $\wedge$ CLOSE_TO(JOHN, x)

The other way around is shown in (44). If John is close to the union of the regions of houses, there is also at least one house, to which John is close to.

(44) John is close to a house. ⇒
$\exists x$: house(x) $\wedge$ CLOSE_TO(JOHN, x)

An anti-additive relation is OUTSIDE , an example of this relation is shown in (45). We assume the interpretation of OUTSIDE as given in (32).

(45) John is outside a house. $\Leftrightarrow$
$\forall x : \text{house}(x) \rightarrow \textsc{outside}(\textsc{john},\ x)$

If John is outside the region of houses, the eigenspace of every house is also outside the eigenspace of John. The other direction of the entailment-arrow is also true, due to the symmetry of the $\cap$ in the definition of the OUTSIDE relation.

5. LOCATIVE PREPOSITIONS AND MONTAGUE SEMANTICS

An explanation about LOC and giving some examples of full semantic derivations.

When combining the theory on LPs with Montague semantics an issue occurs. Let's observe the sentence The man is inside the garage. Usually in Montague semantics the definite NPs The man and the garage are semantically interpreted as entities. However, the function corresponding to inside (INSIDE, as mentioned in §4.2 in (29)) requires two regions as it's arguments, and not two entities.

5.1 Interpretation of Locative Relations

Because of this issue the LOC-function (location function) is introduced. The LOC-function maps entities to their corresponding eigenspace. An example of how this would work is given here. Let's assume the following lexicon:

Lexical item	**Syntactic type**	**Semantic Interpretation**	**Semantic type**
The_man	np_{def}	m	e
is_inside	$(np_{def}\backslash s)/np_{def}$	$\lambda x.\lambda y.\text{INSIDE}(\text{LOC}(x),\text{LOC}(y))$	eet
the_garage	np_{def}	g	e

Using this lexicon the semantic interpretation of the sentence The_man $\otimes$ is_inside $\otimes$ the_garage would be (46).

(46) $\lambda x.\lambda y.\text{INSIDE}(\text{LOC}(x),\text{LOC}(y))(g)\ (m)$

Which reduces via applications to (47). This is exactly what you would expect from the theory on LPs.

(47) $\text{INSIDE}(\text{LOC}(m),\text{LOC}(g))$

This entire approach only works if the entities are actually assigned an eigenspace. Also the example shown here only deals with definite NPs. Indefinite NPs are not yet dealt with. For this reason the PEH is expressed in the LOC-function. This is very clear in the formal definition of LOC for predicates/properties, which is shown in (48).

(48) *Let P be a predicate or property consisting of locatable entities and P_e its extension.*

$\textsc{loc}(P)= \bigcup_{x\in P_e} \textsc{loc}(x)$

In words this would be: The $\textsc{loc}(P)$ of predicate P refers to the union of the eigenspaces of every element in P.

There is an important condition to this definition, namely that all x in P_e are *locatable*. An entity x is locatable if the second LOC-function, that assigns entities an eigenspace, assigns x a non-empty eigenspace. Basically this means that the eigenspaces of all elements of the property/predicate are known by the interpreter of the sentence. To show that the treatment of indefinite NPs is quite similar to that of definite ones, using LOC, we assume the following lexicon:

Lexical item	**Syntactic type**	**Semantic Interpretation**	**Semantic type**
The_man	np_{def}	m	e
is_inside	$(np_{def}\backslash s)/np_{indef}$	$\lambda x.\lambda P.\textsc{inside}(\textsc{loc}(x),\textsc{loc}(P))$	$e(et)t$
a_garage	np_{indef}	GARAGE	et

Using this lexicon the semantic interpretation of the sentence The_man ⊗ is_inside ⊗ a_garage is (49).

(49) $\lambda x.\lambda P.\textsc{inside}(\textsc{loc}(x),\ \textsc{loc}(P))(\textsc{garage})\ (m)$

Which reduces via applications to (50).

(50) $\textsc{inside}(\textsc{loc}(m),\ \textsc{loc}(\textsc{garage}))$

From interpretations like above, (46) and (49), entailments can be deduced. This can be done through properties of the relations, like additivity or monotonicity, as mentioned in §4.3. An entailment that can be deduced through anti-additivity for (49) is (51).

(51) $\exists x : \textsc{garage}(x) \wedge \textsc{inside}(\textsc{loc}(m),\ \textsc{loc}(x))$

Also the truth value of the relation can be calculated by further reduction of INSIDE. This is shown in (52).

(52) $\textsc{loc}(m) \subseteq \textsc{loc}(\textsc{garage})$

At last the interpretation of a spatial sentence using a measuring phrase is shown. We look for this at sentence (53).

(53) The man is less than 20km from a garage.

We assume the same types and interpretation for The man and a garage as mentioned before. From Mador-Haim and Winter (2012) it is nog clear what the exact types of the measure-based spatial relation is, but for now we construct the relation from the measuring phrase LESS_THAN_20KM and the FROM relation. For the construction of (54) we look at (36).

(54) LESS_THAN_20KM_FROM(A,B)= DIST(A,B) $\in \{r : r < 20\}$

The types for this relation are assumed the same as IS_INSIDE in the previous example. The composition of (53) is similar to that of (49) except that the result is a more complex function. This is shown in (55).

(55) LESS_THAN_20KM_FROM(LOC(m),LOC(GARAGE))= DIST(LOC(m),LOC(GARAGE)) $\in \{r : r < 20\}$

This function can then again be reduced to a truth value. The goal of this chapter was to give insight in the theory in chapter 4 by means of some more elaborated examples.

6. CONCLUSIONS

The goal of this thesis was to give insight in the issues involved in the formal treatment of spatial expressions, in particular locative prepositional phrases. It looked into more detail to the model for the interpretation of locative prepositions proposed by Zwarts and Winter (2000) and its extension to the treatment of indefinites of Mador-Haim and Winter (2012).

Some of the major issues that are not yet dealt with properly in the current model, and might be good topics for future research are, the interpretation of the INSIDE relation with respect to cases when the reference object is not a subset of the located object. Also the phenoma described in §4.1 on the mereological characterisation of wholeness remains a difficult, and yet unsolved, matter.

BIBLIOGRAPHY

Casati, R. and Varzi, A. C. (1999). *Parts and Places: The Structures of Spatial Representation*. MIT Press.

Johansson, I. (2004). On the transitivity of parthood relations. In Hochberg, H. and Mulligan, K., editors, *Relations and Predicates*, pages 161–181. Ontos/Lancaster, Frankfurt.

Kracht, M., Comrie, B., Dench, A., Eckardt, R., Fong, V., Hamm, F., Helimski, E., Kiparski, P., Ranta, A., Strigin, A., Zimmermann, I., Zwarts, J., and Domokos, M. J. (2002). On the semantics of locatives. *Linguistics and Philosophy*, 25:157–232.

Mador-Haim, S. and Winter, Y. (2012). Locating sets: Spatial semantics of indefinites and collective descriptions. *Unpublished manuscript*.

Nam, S. (1995). *The Semantics of Locative Prepositional Phrases in English*. PhD thesis.

Nam, S. (1997). Ways of locating events. *Shafto, MG and Langley, P.(eds.)*.

Zwarts, J. and Winter, Y. (2000). Vector space semantics: a modeltheoretic analysis of locative prepositions. *Journal of Logic, Language and Information*, 9:169–211.