

A THEORETICAL INVESTIGATION ABOUT THE NOTION OF PARTS AND WHOLES: MEREOLOGICAL AND MERONYMIC RELATIONS

Mauricio Barcellos Almeida
Universidade Federal de Minas Gerais, Brasil

Renata Abrantes Baracho
Universidade Federal de Minas Gerais, Brasil

Abstract

Within the realm of Information Science, information retrieval is a seminal issue. Knowledge organization systems are instruments that organize knowledge by connecting concepts through semantic relations for purposes of information retrieval. One of the most important of these semantic relations is the so-called part-whole relation. In this paper, we revisit some peculiarities of part-whole relations that are often overlooked by the Information Science community. In order to do this, we provide a theoretical investigation of two perspectives used to explain the notion of parts and wholes: a formal perspective, which is based on the philosophical study usually called mereology; a non-formal perspective, which is based on the linguistic study about a relation called meronymy. We discuss the relationship between these perspectives through the issue of transitivity, which is an important property of part-whole relations for information retrieval. We find that these perspectives, although distinguished, are somehow complementary. The results of our analysis suggest that the choice for either a formal or a non-formal perspective could be based on a pragmatic criterion in the scope of development of knowledge organization systems. We conclude by offering some considerations correlating two main sorts of these systems, namely ontologies and thesauri.

1.0 Introduction

The human understanding of the world depends on the ability to identify entities and characterize relations among them. Semantic relations are meaningful associations among entities. A major reason to study semantic relations is the essential role they play in the processes that people use to represent knowledge. If concepts representing entities are the building blocks of the human conceptual structure, semantic relations are the glue that holds them together. Examples of

prototypical semantic relations employed to structure the world are both *class inclusion*, and *part-whole*.

This paper examines the semantic relation generically called part-whole, which deals, as its name suggests, with things treated as wholes and the parts connected to it. The study of part-whole relations dates back to ancient Greek philosophy, when it was investigated in the scope of a discipline named *mereology* (from the Greek word “*meros*” meaning “*part*”). Nowadays, the term mereology is still used to refer to the formal study of a whole and its parts conducted within logic and philosophy (Smith; Wolfgang, 1982). Indeed, the study of part-whole relations has been a subject of interest of many fields of knowledge, encompassing investigators whose concerns involve entities, words, meaning, or the mind. Among these investigators, one can identify, in addition to philosophers, also linguists and psychologists, and other professionals like cognitive neuroscientists, computer scientists, information scientists, and educators.

The research on part-whole relations has been oriented according to three main approaches (Gerslt; Pribbenow, 1995): i) the logical approach; ii) the psychological approach; and iii) the linguistic approach. The logical approach studies mereological systems, which are used to formalize ontological domains (Simons, 1987) and to perform ontological modeling (Smith, 1993). The second approach, which is called psychological, studies both the use of information about parts in the identification of objects and the partonomic knowledge within the human conceptual system (Twersky, 1990; Twersky; Hemenway, 1984). The third approach is the linguistic one, which deals with natural language semantics for the interpretation of possessive constructions, along with other studies (Cruse, 1986; Winston *et al.*, 1987). While at this point it should be noted that the first and third approaches are emphasized in this paper, the second one is no less important.

The evident observation here is that each of these perspectives carries its own implicit assumptions and research methodologies. Within Information Science, semantic relations are used in knowledge organization systems (KOS) for purposes of information retrieval. In this context, the study of semantic relations seems to be based mainly on linguistic and psychological approaches, as suggested in comprehensive works like Koo and Na (2006) and, Hjørland (2007). Nevertheless, it is not an easy task to draw a clear line between what is a linguistic approach to the

study of semantic relations, and what is a psychological or a philosophical approach (Palmer, 1976).

This paper aims to provide a well-founded theoretical explanation of part-whole notions for information scientists, which we believe to be an essential support for one interested in coping with the several types of available KOS, including ontologies (Souza *et al.*, 2012). What is missing is such a theoretical account that combines both the philosophical and the linguistic points of view, which are not usually contemplated together in the literature. We intend to investigate some peculiarities of part-whole relations, which are well known to linguists and philosophers, but that unfortunately often tend to be overlooked by the Information Science community.

Therefore, two perspectives about the notion of part-whole are considered here. The first one, which we call *formal*, has a logical orientation. It considers semantic relations to be a matter of analytic or objective truth, and it is concerned with the formalization of relations. The second perspective, which we call *non-formal*, has a psycholinguistic orientation. It acknowledges that semantic relations among words are mentally and linguistically expressed, and it is concerned with their use in the human mind within several contexts.

After the presentation of these perspectives, we point out some potential drawbacks of formal approaches, focusing on the discussion about the property of transitivity. We use the issue of transitivity as a way to stress the differences between formal and non-formal approaches. Indeed, transitivity is by far the most important property of part-whole relations for information retrieval, insofar as it allows query expansion through transitive chains of concepts (Stock, 2010). We find that formal and non-formal approaches, even though distinguished, do not exclude each other. In some senses, they are actually complementary approaches. We conclude our discussion by suggesting that the choice for one or another way to deal with part-whole notions, as well as their characterization and properties, could be based on a pragmatic criterion in the scope of development of KOS. Finally, some brief considerations correlating ontologies and thesauri are presented. We hope this paper can contribute by gathering together some of the main aspects in the study of semantic relations, in particular part-whole relations.

As this paper surveys different fields of research, some elucidation about the different terms used to refer to the part-whole notion is needed. So, in addition to the

term mereology, there are other denominations associated with this notion, namely, *part-whole* itself, *meronym* and *partonomy*. Even though these terms are often used interchangeably, there are variations in their meanings. In several contexts, *part-whole* is the general term used to mean all the other terms just mentioned. *Part-whole* is also the term used to stand for the relations that hold among things of the world in the scope of mereology. *Meronym* is the term used by linguists to stand for the relation that deals with how parts of words, or word meanings, are related. Moreover, the term *partonomy* is sometimes found within the psycholinguistic realm where it is used to refer to part-whole hierarchies of objects created in our minds. In the rest of this paper, as much as possible, we try to follow these notations when referring to the different relations involving the notion of parts.

The remaining part of the article is organized as follows: section two describes the most well-known mereological theories, while section three studies meronymic relations. Section four discusses the part-whole property of transitivity, presenting the points of view of both formal and non-formal approaches. Finally, section five offers our final remarks and possibilities for future research.

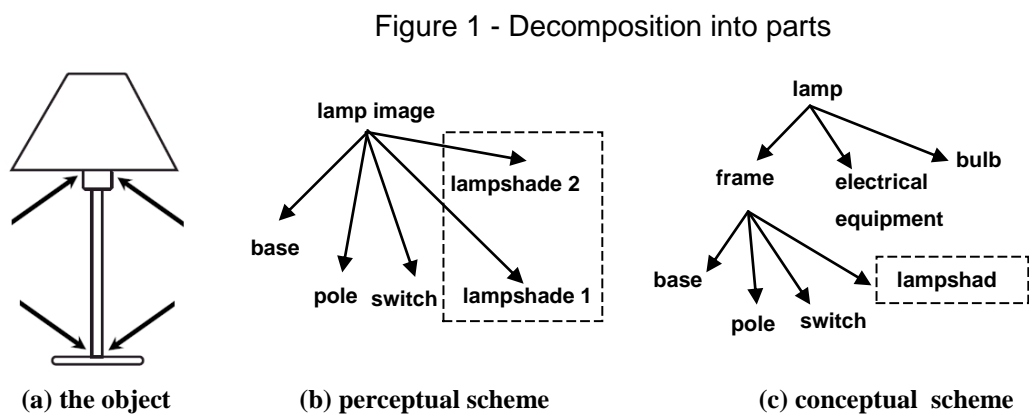
2.0 Formal part-whole relations

Mereology is the theory that deals with the relations of parts to the whole and the relations of part to part within a whole, from a formal point of view. Mereology has been studied since ancient Greece, but it reaches modern times only with the work of *Edmund Husserl* in the early twentieth century. The most accepted mereological theories are, however, the subsequent ones proposed by *Stanisław Leśniewski* in 1916, and by *Henry Leonard* and *Nelson Goodman* in 1940.

There are two main groups of principles one can use to explain the relations between parts and wholes: *principles of decomposition*, which take one from a whole to its parts; and *principles of composition*, which take one from the parts to the whole. These principles, in addition to some basic notions, give rise to the core of mereological theories. In this section, after presenting an overview of mereological relations (section 2.1) and a required background (section 2.2), we investigate the three best known mereological theories, namely: *basic mereology* (section 2.3), *extensional mereology* (section 2.4) and *classical mereology* (section 2.5). The last one corresponds to the classical systems due to *Leśniewski*, and to *Leonard* and *Goodman* of which a simplified view is presented.

2.1 Mereological relations: an overview

Even though one takes a formal framework as a first step to understand the part-whole relation, it is worth emphasizing that any approach like this relies on very intuitive notions that people natively possess. Indeed, the relation of part to whole is one of the most basic and intuitive notions, which plays an important role both in the human conceptual system (Flavell; Markman, 1983) and in human visual perception (Biederman, 1987). Figure 1 depicts an object (a) and two different possibilities of division into parts, according to either a perceptual (b) or a conceptual scheme (c).



Source: adapted from Pribbenow (2002)

Thus, in order to speak about the world, one can instinctively separate any entity into parts: there are parts of objects, parts of events, of abstract entities, of temporal or spatial entities, to mention but a few. Some simple examples can illustrate this relation, as presented in Figure 2.

Figure 2 - Examples of typical wholes and parts

Whole	Part
a (certain) man	his head
a (certain) tree	its trunk
a house	its roof
a mountain	its summit
a battle	its opening shot
an insect's life	its larval stage
a novel	its first chapter

Source: Simons (1987, p.10)

However, one can conclude through a more attentive observation that the exact meaning of the term "*part*" is not so clear considering the multitude of situations

in which it is employed. The term part can be used to indicate several possibilities involving attachment, detachment, salience, demarcation, and connection; all of them subject of mereological studies. Examples of these possibilities are showed in the following sentences (Varzi, 2009):

- (1) The handle is part of the mug.
- (2) This cap is part of my pen.
- (3) The left half is your part of the cake.
- (4) The cutlery is part of the tableware.
- (5) The contents of this bag are only part of what I bought.
- (6) That area is part of the living room.
- (7) The outermost points are part of the perimeter.
- (8) The first act was the best part of the play.

In sentence (1) the part is attached to the whole, while in sentence (2) the part is detached from the whole; (1) and (2) are examples in which the part is cognitively salient in relation to the whole; in (3) the part is arbitrarily demarcated in relation to the whole; in (1) and (3) the part is self-connected to the whole, while (4) is an example of a part disconnected from the whole; (1) to (5) are examples of material parts, and (6) is an example of an immaterial part; (1) to (6) are examples of parts extended in relation to the whole, while (7) is an example of an unextended part; (1) to (7) are examples of spatial parts, and (8) shows a temporal part.

There are other situations in which the use of the term “part” can be still more controversial (Varzi, 2009):

- (9) The clay is part of the statue.
- (10) Gin is part of a martini.
- (11) Writing detailed comments is part of being a good referee.
- (12) The conclusion is part of the argument.
- (13) The domain of quantification is part of the model.
- (14) The suffix is part of the official file name.
- (15) Rationality is part of personhood.

Sentences (9) to (11) may not be considered to be part-whole relations, even though in some occasions they may be interpreted this way. Sentence (9) shows a relation of constitution; sentence (10) is a case of composition; sentence (11) is a case of inclusion. Examples (12) to (15) exhibit another feature of part-whole relations: it seems that there is no ontological restriction with respect to the relata of

the relation. In addition to being material entities, events, spatial regions, as in sentences (1) to (8), they can also be propositions, sets, types or properties, as one can notice in sentences (12) to (15).

Even though the mereological status of some relations is a matter of controversy, some basic principles can be identified. From such a basis, one can reach more sophisticated theories, which are able to encompass a diversity of notions.

2.2 Background

In order to explain the most basic theory of mereology, we need to consider a certain level of formalization. This level is becoming more complex insofar as we continue to explain the more advanced theories in later sections (sections 2.4 and 2.5). We assume that readers do not have training in logic used in philosophy or mathematics, which in general overlap each other. So, throughout the text, we present formal sentences of symbolic logic together with the respective explanations in natural language. Also, concepts required to understand the development of the explanation are provided, as well as references when necessary. Finally, we apologize to those readers trained in such matters by the simplicity of our basic explanations.

First, we need to explain certain usual definitions in logic, namely, *first-order logic*, *predicates*, *quantifiers*, and *logical operators*. The definitions presented here are mainly based on Gensler (2001), but any book of logic can provide the basic notions one needs to understand mereological theories.

Basically, any logic consists of a language together with a deductive system. In general, the language is a subset of a natural language, like English. The deductive system aims to capture the correct inferences for the given language. *First-order logic* is a system of symbolic logic that uses *predicates* and *quantifiers*.

In order to understand *predicates*, one can consider a sentence containing a subject plus a predicate: “*the dog is barking*”. The subject of this sentence is “*the dog*” and the predicate is “*is barking*”. Then, a symbol representing a constant is assigned to the subject, such as *d* for “*dog*”; and another symbol is assigned to the predicate, such as *Bx* for “*x is barking*”. So, we can symbolize the sentence “*the dog is barking*” by “*Bd*”.

With respect to *quantifiers*, there are two of them: the *universal quantifier* and the *existential quantifier*. The former is symbolized by \forall , it can be read as “for every $x...$ ” and it means “all”; the latter is symbolized by \exists , it can be read as “there is some $y...$ ” and it means “some”. An example of usage of universal quantifiers is the formal sentence $\forall x(Px \rightarrow Vx)$, which can be read, for example, as “for every x , if x is a potato, then x is a vegetable” or simply “all potatoes are vegetables”. An example of usage of existential quantifiers is the formal sentence $\exists x(Px \wedge Cx)$, which can be read, for example, as “there exists an x such that x is a potato, and x is cut” or simply “some potatoes are cut”.

Finally, *logical operators* are essential for understanding the connection of elements in logical sentences. There is more than one symbology to represent the operators. We adopt the most traditional one, and always present it followed by its meaning expressed in natural language: “ \rightarrow ” stands for “*implies*” or “if ... then”; “ \leftrightarrow ” stand for “*if and only if*”; “ \neg ” stands for “*not*”; “ \wedge ” stand for “*and*”; “ \vee ” stand for “*or*”. This list is not complete, but it meets our needs here.

2.3 Basic Mereology

At this moment, we are ready to formulate the most basic mereological theory. All formalisms presented henceforth are based on Simons (1987), Varzi (1996), and Casati and Varzi (1999). It is worth mentioning that some details are omitted. The initial context consists of a *first-order language*, in which a predicate P is defined as the *part-whole relation*. Within this context, a single part-of relation between two elements x and y is represented here by Pxy , which is read “ x is part of y ”. If the term “*part*” stands for the type of relations exemplified in section 2.1, then it stands for *partial orderings* (Bittner, 2011). A partial ordering is a binary relation (a relation between elements of two sets), which has the properties of *reflexivity*, *transitivity*, and *asymmetry*. Formally, this can be written as presented in Table 1 (here and in the future, we will drop the quantifiers):

Table 1 - Basic mereological characterizations

Ref.	Property	Formal representation	Natural language translation
(1)	Reflexivity	Pxx	x is part of x
(2)	Transitivity	$(Pxy \wedge Pyz) \rightarrow Pxz$	if x is part of y and y is part of z , then x is part of z
(3)	Asymmetry	$(Pxy \wedge Pyx)$	if x is part of y and y is part of z ,

	$\rightarrow x=y$	then x is equal to z
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When describing these properties, we consider the objects “x” and “y”, and a relation “R”. A relation is *reflexive* if it relates an item to itself as in Rxx , for example: “John resembles himself”. A relation is *transitive* if Rxy and Ryz entail Rxz , for example: “if John is in front of Harry” and “Harry is in front of Bill”, then “John is also in front of Bill”. A relation is *symmetric* if it holds for the related items in both directions, that is, Rxy entails Ryx , for example: “if John is married to Mary, Mary is married to John”. It is *asymmetric* otherwise (Palmer, 1976).

The formal sentences in Table 1 capture some intuitions that people have involving the just mentioned properties and the part-whole relation. The reflexivity property means that everything is part of itself; the transitivity property means that any part of any part of a thing is itself part of that thing; and the asymmetry property means two distinct things cannot be part of each other.

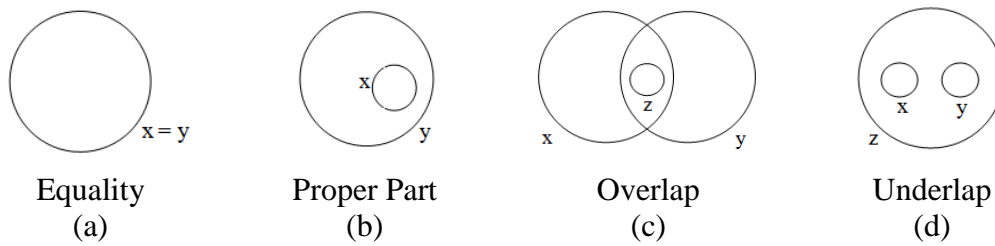
The theory embedded in Table 1 is usually called *Basic Mereology*, and sometimes referred to as *Ground Mereology*. It is the common basis for any part-whole theory. From the basic properties (1) to (3) some other properties can be added to our framework, as shown in Table 2. Because it is not important for our purposes here, we omit an explanation about how (4) to (7) can be obtained by definition from (1) to (3).

Table 2 - Additional mereological characterizations

Ref.	Property	Formal representation	Natural language translation
(4)	Equality	$EQ_{xy} = P_{xy} \wedge P_{yx}$	x is equal to y corresponds to a situation in which x is part of y and y is part of x
(5)	Proper part	$PP_{xy} = P_{xy} \wedge \neg P_{yx}$	x is proper part of y corresponds to the situation in which x is part of y and y is not part of x
(6)	Overlap	$O_{xy} = \exists z(P_{zx} \wedge P_{zy})$	x overlaps y corresponds to the situation in which there exists a z such that z is part of x and z is part of y
(7)	Underlap	$U_{xy} = \exists z(P_{xz} \wedge P_{yz})$	x underlaps y corresponds to the situation in which there exists a z such that x is part of z and y is part of z

These extra properties (TABLE 2), in addition to better characterizing the part-whole relation according to the basic mereology, are important for further developments in the scope of more sophisticated theories (sections 2.4 and 2.5). For the sake of clarity, Figure 3 elucidates the correspondent notions in a graphical form:

Figure 3 - Properties applied to a part-of relation between x and y



As one can notice, again, all of these properties try to capture intuitive notions about being part of something. “*Equality*” means that if two objects are, at the same time, part of each other, they are actually the same object. In Figure 3(a), x and y are equal and then they are represented by a single line. “*Proper part*” means that x is part of y but not identical to y , as depicted in Figure 3(b). For example, your hand is part of you, but it is not (and never will be) you as a whole. “*Overlapping*”, intuitively, means that two things partially occupy the same space. In Figure 3(c), one can notice that there is a thing (z) that is part of both other two things (x and y). For example, two intersecting roads have as the common part the place where there is a junction. On the other hand, “*underlapping*” means that two things are both part of another bigger thing. In Figure 3(d), x and y are both part of z . For instance, your left thumb and index finger underlap, since they are both parts of you.

It is worth mentioning that Figure 3 shows only one possibility for overlapping, but indeed there are four possibilities. The same occurs with underlapping, which counts five possibilities. We present only the more intuitive ones, for the sake of simplicity. The full framework is available in Varzi (1996).

2.4 Extensional mereology

This section presents a first extension for the basic mereology, which was described before (section 2.3). This extension is named *Extensional Mereology*. It involves the so-called *decomposition principles*: these are principles that take one

from a whole to its parts. The notion behind decomposition is that whenever something has a proper part, it actually has more than one. In other words, nothing can have a single proper part. This implies the existence of a remainder between a whole and its proper part, in any process of the decomposition of wholes. This remainder is usually termed *mereological difference*.

There is more than one possibility to formally capture the intuition behind mereological difference. The most accepted possibility is named *supplementation* (see TABLE 3, first line). According to the principle of supplementation, every proper part of a whole must be supplemented by another part, which is disjointed from the first one. It is exactly this last characterization – the disjointedness – that captures the notion of mereological difference.

There is a slightly different version of the supplementation principle known as *strong supplementation*, which provides an even stronger characterization. The principle of strong supplementation (see TABLE 3, second line) corresponds to the idea that if an object fails to include another one among its parts, then there must be a remainder.

Table 3 - Extensional characterizations – supplementation

Ref.	Property	Formal representation	Natural language translation
(8)	Supplementation	$PPxy \rightarrow \exists z(Pzy \wedge \neg Ozx)$	if x is a proper part of y , then there exists a z such that z is part of y and z does not overlap x
(9)	Strong supplementation	$\neg Pxy \rightarrow \exists z(Pzy \wedge \neg Ozx)$	if x is not part of y , then there exists a z such that z is part of y and z does not overlap x

When the strong principle of supplementation is added to basic mereology, one can reach the already mentioned *Extensional Mereology*. The strong principle of supplementation gives rise to a property named *extensionality*. There is a formalization of the property of extensionality, which is not developed here. For our purposes, it is enough to say that the property of extensionality ensures: i) that entities are completely defined by their parts; ii) no composite objects with the same proper parts can be distinguished.

2.5 Classical mereology

In this section we present another extension for basic mereology, which is named *Classical Mereology*. It involves *composition principles*: these are principles that take one from the parts to the whole. The notion behind composition is that

whenever there are things, there exists a whole that is formed exactly by those things. In other words, there is a unique sum for arbitrary entities. The uniqueness is guaranteed by the property of extensionality, implied by the principle of supplementation in the scope of extensional mereology (section 2.4). The existence of this sum implies that there is always a fusion between two or more parts. Such a fusion is known as *mereological sum*.

Similar to extensional mereology, there is more than one possibility to capture the notion behind a mereological sum. The weakest option is named *upper bound* and a less weak option is named *sum*. Table 4 presents these two possibilities.

Table 4 - Classical characterizations – mereological upper bound and mereological sum

Ref.	Property	Formal representation	Natural language translation
(10)	Upper Bound	$UB_{xy} \rightarrow \exists z(Pxz \wedge Pyz)$	if x is an upper bound of y, then there exists a z such that x is part of z and y is part of z
(11)	Sum	$S_{xy} \rightarrow \exists z \forall w (Ozw \leftrightarrow Oxw \vee Oyw)$	if x is a sum of y, then there exists a z, for every w, such that z overlaps w if and only if x overlaps w or y overlaps w

The first line of Table 4 presents the *mereological upper bound* notion. A mereological upper bound of two objects is another object of which both the original ones are parts. The *mereological sum* is a mereological upper bound of which any part overlaps one of the two individuals summed (Gotts; Cohn, 1995). In other words, a mereological sum between two objects must be something composed exactly of their parts and nothing else.

These aforementioned formulations try to capture the notions of a sum of objects that form a whole. However, they are not enough for this, insofar as there are difficulties in expressing such a principle in common first-order logic. In order to gain access to classical mereology, the formulation must consider *infinitary bounds* and *infinitary sums*. These infinitary elements demand the use of an *infinitary logic*, which deals with infinitary operations, that is, operations that take an infinite number of input values to produce an output (Bell, 2012). Using these tools, one can express the

strongest version of all composition principles, namely, *unrestricted composition*, which allows arbitrary sums. The machinery needed to understand this last type of composition it is not presented here, because the inherent difficulty in explaining it in just one paper. In doing this task, one can reach the already mentioned classical mereology systems (Leśniewski, 1916; Leonard; Goodman, 1940).

3.0 Non-formal part-whole relations

From a linguistic point of view, there are two different but related aspects of meaning that should be considered when analyzing relations. The first one, called *reference*, deals with the relations between the linguistic elements (words, sentences) and the non-linguistic world of experience. The second, named *sense*, relates to the complex system of relations that holds between the linguistic elements themselves, mainly words. Some authors name this last type of relation *sense relation*, because they believe these relations hold among senses of words (Lyons, 1977). However, the literature of psycho-linguistic orientation generally uses either the term *lexical relation* or *semantic relation* to refer to *paradigmatic relations* among words (Khoo; Na, 2006).

Paradigmatic relations refer to words which are members of the same grammatical category. They can be defined in contrast to *syntagmatic relations*, which describe relations between words of different grammatical categories. Syntagmatic relations go together in a syntactic structure such as, for example, a sentence (Murphy, 2003). Figure 4 illustrates a scheme with paradigmatic and syntagmatic relations in a set of sentences.

The explanation presented here is a very simple one for such important concepts. However, a detailed explanation of this topic is beyond the goals of this paper. A more comprehensive explanation can be found in Lyons (1968), a classic of linguistics.

Figure 4 - Types of relations among words

Relations	← Syntagmatic →					
↑ Paradigmatic ↓	A	dog	fell	in	this	chair
	The	cat	sat	on	the	mat
	That	man	ate	by	A	hat

In this section we focus on the lexical relation named *meronymy*. The mereological relation, as explained in the prior section (section 2), is a relation that

links two individual entities, that is to say, it is an extra-linguistic relation. Meronyms, on the other hand, are intra-linguistic relations. It is the lexical relation that holds among words, in addition to be the lexical correspondent of the mereological relation.

In the remaining part of this section, we first present an overview of meronymic relations (section 3.1). Then, we characterize meronyms by comparing them with similar relations, by describing their ability to form chains and by explaining how they are established among lexical units (section 3.2). Finally, the main types of meronyms found in the literature are presented (section 3.3).

3.1 Meronymic relations: an overview

Even though meronyms have received less attention from theorists, several questions about them have been posed: i) if the meronymic relation is actually a family of relations and, if so, how can these relations be distinguished from other semantic relations?; ii) what does the term “*part*” really mean?; iii) what are the relata of meronymic relations? There is no consensus about these questions, but some preliminary considerations are in order.

Some authors believe that meronyms are not a single relation but several relations more or less similar to each other (Cruse, 1986; Winston *et al.*, 1987). Some authors advocate that even though different types of meronymic relations seems to be apparent, the criteria used to develop typologies of relations do not satisfactorily differentiate those types (Murphy, 2003). We will return to the claim that the meronym is actually a family of relations in section 3.3, and also when discussing transitivity in section 4.1.

With respect to meaning, the term “*part*” is vague and used to express a variety of distinct semantic relations. It is only the most general of a large number of terms that can be used to express meronymic relations. *Roget's Thesaurus* lists approximately 400 synonyms for *part* and there are at least 40 related terms narrower in scope than *part* (Winston *et al.*, 1987).

With respect to the relata of the meronymic relation, the abundance of terms representing linguistic entities – words, lexemes, lexical items, lexical units, lemmas, to mention but a few – casts doubts on what semantic relations really relate. The relata in a meronym are lexical items that should be delimited syntagmatically, that is, one must be able to state in a sentence where the boundaries of lexical items are located. On the one hand, some authors suggest that the meronym holds among

nouns (Cruse, 1996); on the other hand, some of them also consider verbs in meronyms, since they can be nominalized, for example: the gerund “dating” is part of “adolescence” (Winston *et al.*, 1987).

Although the literature is not very precise, it seems to be an agreement that meronymic relations are relations among words. Indeed, the term “*word*” is often used to indicate lexical items, but this is not really accurate, insofar as the lexicon of a language must contain linguistic expressions that are greater or smaller than words. However, it seems reasonable to refer to lexical relations as relations among words considering that claims made about words may be extended to non-word lexical items (Murphy, 2003).

So far in this section, we have presented some basic features that can help one in the understanding of meronymic relations. In the next section (section 3.2), we pursue a more detailed characterization of meronyms.

3.2 Characterization of meronyms

Within the realm of semantic relations, it is quite a complex task to identify what relations hold between two lexical items. Departing from intuition, one can observe that some words are more closely related in meaning than others. Also, some labels have a wider scope of application than others, for example: *thing* is wider than *furniture*, which in turn is wider than *table*. In this situation, one can recognize the most basic semantic relation, namely, *hyponym*. It holds when two lexical items stand in the relation of class to subclass, for example, the pair *apple-fruit*. In addition, hyponym is a hierarchical relation, that is, words higher in the hierarchy have wider scope than those they dominate.

Meronym is often described in comparison with hyponym, as a type of hierarchical relation. An example of a meronym is the pair *arm-body*. The meronym has two directions: *arm* is a meronym of *body* and *body* is a *holonym* of *arm*, and the relation between these two items is a meronymic relation. The difference of a meronym to a hyponym is clear when the lexical units involved are nouns denoting physical objects: an *arm* is not a kind of *body* but a part of a *body*.

This is a possibility to characterize meronyms, but there are others. In the remaining part of this section, we aim to investigate additional features of meronyms by shedding some light on: the establishment of meronymic relations (section 3.2.1);

the ability of meronyms to form chains (section 3.2.2); and, the distinction of meronyms from other similar relations (section 3.2.3).

3.2.1 *The establishment of meronymic relations*

A great deal of meronymic information is stored in human memory. So, a person that knows the meaning of referents of words can simply remember, for example, that a *keyboard* is part of a *piano* or an *index* is part of a *book* (Miller; Johnson-Laird, 1976). If people don't know the meaning of the words involved, they must collect empirical evidence in order to establish the relation or verify its correctness. But, this mere observation do not produce a criterion to establish meronymic relations.

Two test-frames can be used to guarantee the establishment of a meronymic relations among sentences, even though the test excludes some intuitive cases of parts and wholes (Cruse, 1986).

The first proposed test-frame considers a sentence in the form "*A Y has Xs*" (or *an X*). Examples of this test-frame are sentences like *A book has pages*, where Y=book and Xs=pages. This first test-frame, however, accepts other attributes that are not parts. For example, the sentence *A wife has a husband* has the form suggested for the first test-frame but do not denote a meronymic relation. The second test-frame considers a sentence of the form *An X is a part of a Y*. Examples of this test-frame are sentences like *A huge bank balance is a part of his attractiveness to women*, where X= huge bank balance and Y= his attractiveness to women.

Only real meronyms satisfy both frames. An example is the pair of sentences *A hand has fingers / A finger is part of a hand*. A general definition of meronyms in this context is (Cruse, 1986, p.160): "X is a meronym of Y if and only if sentences of the form *A Y has Xs* [1st test-frame] and *An X is part of a Y* [2nd test-frame] are normal when the noun phrases *a X and a Y* are interpreted generically".

Meronyms also can be seen as relations between contextually construed meanings. Thus, in order to verify the establishment of a meronymic relation one can test it against the following definition (Croft; Cruse 2004, p. 160):

If A is a meronym of B in a particular context, then any member 'a' of the extension of A either maps onto a specific member 'b' of the extension of B of which it is construed as a part, or it potentially stands in an intrinsically construed relation of part to some actual or potential member of B

The term “intrinsically” in the definition above concerns necessity, for example, a *nose* is intrinsically part of a *face*.

In addition, a set of other factors should be considered for identifying the establishment of a meronymic relation *x* as part of *y* (Croft; Cruse, 2004): i) the boundary of *x* does not transgress the boundary of *y*; ii) *x* shares all its substances with *y*; iii) the boundaries of *x* can be demonstrated in a well-formed whole of *y*; iv) the more salient the discontinuity between *x* and not-*x*, the better the part; v) the greater the internal cohesion of *x*, the better part; vi) *x* has a definable function relative to *y* (for example, a *wing for flying*); vii) *x* is autonomous, that is, an exact replica of *x* also count as parts; and viii) there is type-consistency between *x* and *y* (parts of objects are objects, part of processes are processes).

3.2.2 *The ability of meronyms to form chains*

Meronyms can be characterized by their ability to generate chains of elements. However, there is no general principle that enables one to decide, with reference to a particular set of lexical units, whether they constitute part-whole chains in the vocabulary.

A basic meronymic chain has the form: *A is part of B, B is part of C, C is part of D*, and so on. A chain has a smallest part, which itself has no other parts, and also there is a largest whole (Bierwisch; Heidolph, 1970). For example, *a fingertip is a part of a finger, a finger is a part of a hand, a hand is a part of an arm, an arm is a part of a body*. As one can easily notice, meronymic chains have a beginning and an end. The problem is to determine the location of the end of such a chain. The decision of where boundaries of an ultimate whole are situated depends on several details that are far from clear. However, there are some possibilities to identify these boundaries.

In order to determine the sequence of a meronymic chain, one can observe the *scope of predication* of each part. A constituent element *A* of a chain *W* is an *immediate part* of another element *B*, and *B* is an *immediate whole* of *A* (Croft; Cruse, 2004). For example, a *finger* is an immediate part of *hand*, and a *hand* is an immediate whole of a set of *fingers*. An immediate whole is the normal scope of predication for its parts. When the construction follows the correct scope of predication the sentence is acceptable, otherwise the sentence is odd. For example, one can consider the following sentences: *a body has two arms; a hand has five fingers; a finger has three knuckles and a fingernail; an arm has five fingers; a body*

has twenty-eight knuckles. As one can notice, the first three sentences are acceptable, but the last two are not.

Another possibility that could help in determining the boundaries of a meronymic chain is to use the notion of *type-consistency* (Croft; Cruse, 2004). In most of situations it is possible to think of a smaller portion than the ultimate one: for instance, *fingertips* as composed of *skin*, *nerve fibers*, *capillary blood vessels* and so on. However, a reason to not divide *fingertips* into *nerve fibers*, *capillaries* and so on is that they are of the wrong type. Indeed, there is no basic ontology for parts – as Varzi (2009) also noticed (see section 2.1) – and then the rule of thumb to be adopted is to consider the type-consistency between the relata's type. For example, the parts of a *period of time* should themselves be *periods of time*; the parts of an *object* should be *objects*; the parts of an *event* or *process* should be *sub-events* or *processes*; the part of an *abstract entity* should be *abstract entities*; and so on.

There is another relevant notion of type, which accounts for two broad types of parts called *segmental parts* and *systemic parts* (Cruse, 1986). *Segmental parts* are spatially delimited and are typically encountered sequentially as a whole is transversed; they also may have heterogeneous internal consistency. Examples are the externally visible parts of the body, such as *arms*, *legs*, *head*, *trunk* and so on. *Systemic parts* are typically spatially interpenetrating, but functionally distinct and typically have a greater internal consistency. Examples in the human body are *the nervous system*, *the vascular system*, and *the skeleton*.

3.2.3 *The distinction of meronyms from other similar relations*

Often meronyms are not clearly distinguished from other semantic relations. There is even a discussion whether some relations are variations of meronyms or if they are completely different from them (Murphy, 2003). Examples of other relations, which are similar to meronyms, are: *possession*, *attribution*, *class inclusion*, *locative inclusion*, *part-piece* and *portion-piece* (Miller; Johnson-Laird, 1976). An example of *possession* is the pair *millionaire-money*, of *attribution* is the pair *mansion-large*. The *locative inclusion* is illustrated by examples representing spatial inclusion, as in *the woman is in the room*, *the room is in the house*, *the house is in the town*. The differences and similarities between two specific relations, namely, *part-piece* and *portion-piece*, can be used to better illustrate the difference of meronymic relations from other types (Croft; Cruse, 2004).

The meronymic relation is a special sub-variety of a more general relation called *portion-whole* relation. When dealing with portions, the basic notion is the containment of one region by another region. Examples are sentences like: *a portion of the cake was given to each of the guests, my portion of the omelet had bits of eggshell in it*. Part is a hyponym of portion, but it concerns a number of non-arbitrary categories that groups together similar items from different wholes. In addition, parts possess common characteristics like shape and size. An example could be: *all the parts of the airplane were carefully packed into crates, ready for shipping*.

Piece likewise can be seen as a hyponym of portion, which, however, do not qualify as a part. A simple example can elucidate these notions: using a hacksaw to cut a typewriter into arbitrary portions, one can obtain pieces of that typewriter, but not parts of it; in order to obtain parts of a typewriter, one needs to use a screw and other tools to disassemble it, detaching its parts. Pieces do not maintain relations with their wholes, other than origin, as for example in: *after the explosion, pieces of the airplane were scattered over a wide area*. Pieces are also distinguished from parts because they are not contemporaneous with their wholes, that is, there are no pieces until the whole is destroyed (Cruse, 1986).

On the one hand, parts and pieces share two common characteristics: *topological stability* and *spatial continuity*. On the other hand, parts are also distinguished from pieces by three characteristics: *autonomy*, *non-arbitrary boundaries* and *determinate function* (Croft; Cruse, 2004).

The characteristic of *topological stability* can be explained by a counter-example: one cannot have a piece or a part of *steam*. To have the characteristic of *spatial continuity* presupposes that one can move from any point within a piece to another point within the same piece without transversing material that does not belongs to the piece. The same occurs if parts are being considered.

In the case of *autonomy*, one can imagine that a piece of a typewriter can be once again integrated to the typewriter, but a replica of that piece would not be considered a piece of that typewriter. This is not true for parts: parts of a typewriter do not need to have pertained to the same original typewriter. Thus, parts are autonomous, pieces are not. The characteristic named *non-arbitrary boundaries* implies that parts are delimited from their sisters' parts by a discontinuity. For example, some parts of the human body are delimited by joints, as such the *forearm* is delimited by *elbow* and *wrist*. Thus, it is possible to point to parts of an integral

whole considering non-arbitrary boundaries. On the other hand, there is no sense in pointing to pieces of an integral whole. The characteristic named *determinate function* suggests that parts have functions relative to their wholes. Examples of this characteristic are *an eye for seeing*, and *a brake for stopping*.

3.3 Types of meronyms

There are several supposed subtypes of meronyms. The number of proposed subtypes varies from two to eight according to different authors (Murphy, 2003). They are often defined based on similar criteria, but received different denominations by different authors. Examples of types of meronyms found in the literature are:

- (1) *necessary meronyms, optional meronyms* (Lyons, 1977);
- (2) *canonical meronym, facultative meronym*, as well as the composed subtypes *canonical-local* and *facultative-local meronym* (Cruse, 1986);
- (3) *intrinsic meronym, extrinsic meronym* (Croft; Cruse, 2004);
- (4) *component-object meronym, member-collection meronym, portion-mass meronym, stuff-object meronym, feature-activist meronym, place-area meronym* (Winston et al., 1987);
- (5) *member-collection meronym, social whole-staff meronym, organization and its head meronym, a whole and its uniform unit meronym, a whole and its center or culmination meronym* (Wanner, 1996);

These previously mentioned types of meronyms are explained in the remaining part of this section. The explanations follow the order of the authors and respective approaches just presented in the list above.

The approaches of Lyons (1977), Cruse (1986) and Croft and Cruse (2004) – items (1), (2) and (3) of the list – can be explained together. In order to do this, we enumerate some sorts of cases that can occur when defining relations, namely: *necessity, optionality, and local senses*.

The *necessity* and *optionality* cases of relations explain some of the meronymic subtypes mentioned. So, there is a difference between a relation connecting *finger* and *hand*, and another connecting, for example, *lake* and *park*. The former embeds a need to consider *finger* as a part of *hand*. But, there is no pressure to connect *lake* and *park*. This idea explains the following subtypes pairs cited in the list: *canonical meronyms* vs *facultative meronym* (item 2 of the list); *necessary*

meronyms vs optional meronyms (item 1); *intrinsic meronym vs extrinsic meronym* (item 3).

In the case of *necessity*, examples are the sentences *A hand has fingers / A door has a handle*. While the first sentence seems normal, the second may seem odd since not all doors have handles. So, a handle is optional for a door whereas fingers are necessary for a hand. Thus, finger is described as a *canonical meronym* of body (as well as body as a *canonical holonym* of finger). In the case of *optionality*, on the other hand, handle is described as a *facultative meronym* of door (and door as a *facultative holonym* of door).

The same basis of the canonical meronym is used to define, respectively, the subtypes *necessary meronym* and the *intrinsic meronym*. Also, using the same basis of facultative meronym, one can understand the subtypes *optional meronym* and *extrinsic meronym*. So, as one can notice, these are examples of the same type of relation termed differently: canonical corresponds to necessary and to intrinsic; facultative corresponds to optional and to extrinsic.

The existence of different local senses in relations produces the composed subtypes *canonical-local* and *facultative-local meronym* (cited in item 2 of the aforementioned list). For example, *handle* is a super-meronym of *door*, since *the handle of doors and drawers* is normal. However, this is normal only because the local senses are close to one another. So, it would be more accurate to describe handle as a *local meronym* of door. Relations involving local senses may vary along the dimension of necessity, for example, handle is a *canonical local meronym* of spoon and a *facultative local meronym* of door, since there is no spoon without handle but there are handleless doors.

The approach of Winston *et al.* (1987) explains several of the meronymic subtypes mentioned in item 4 of the aforementioned list. Three elements, which consider characteristics of the relation of the part to the whole, are employed to make distinctions of meronymic relations: whether the part is *functional* with respect to the whole, whether it is *homeomeric*, or whether it is *separable*. Functional parts are spatially restricted by their function, for example, a *handle* has a function with respect to a *cup* in a limited number of positions. Homeomeric parts has the same kind of thing that works as a whole, for example, the pair *slice-pie* or *crust-pie* (but not *tree-forest*). Separable parts can be separated from the whole, for example, *handle-cup*

(but not *steel-bike*). The three features mentioned can be specified as *yes* or *no*, as shown in Figure 5.

Figure 5 - Types of meronymic relations

Relation	Elements		
	Functional	Homeomeric	Separable
Component / Integral object	Yes	No	Yes
Member / Collection	No	No	Yes
Portion / Mass	No	Yes	Yes
Stuff / Object	No	No	No
Feature / Activity	Yes	No	No
Place / Area	No	Yes	No

Source: adapted from Winston *et al.* (1987)

From the distinctions presented in Figure 5, one can reach a final taxonomy containing the six types of meronymic relations already mentioned: i) *component-integral object*, as in the pair *pedal-bike*; ii) *member-collection*, as in *ship-fleet*; iii) *portion-mass*, as in *slice-pie*; iv) *stuff-object*, as in *steel-car*; v) *feature-activist*, as in *paying-shopping*; and vi) *place-area*, as in *Everglades-Florida*.

The approach of Wanner (1996), which is cited in item 5 of the list, is developed in the scope of the *Meaning-Text Theory*. This is a theory with roots in Natural Language Processing efforts. It departs from the relations distinguished by Chaffin *et al.* (1988) to propose five kinds of meronyms based on the concept of lexical functions (LFs). LFs express lexical co-occurrences through sets of word's paradigmatic and syntagmatic relatives.

The meronymic relations defined in this context are: i) member-collection meronym is named *LF Mult*, for example, *Mult (dog) = pack*, *Mult (vehicle) = fleet*; ii) social whole-staff meronym is named *LF Equip*: it holds between a lexical unit denoting an organization or a functional artifact and its staff; for example, *Equip (aircraft) = crew*, *Equip (hospital) = staff*; iii) organization and its head meronym is named *LF Cap*: it holds between an organization or a functional artifact and its head; for example, *Cap (ship) = captain*, *Cap (faculty) = dean*; iv) a whole and its uniform unit meronym is named *LF Sing*; it is a quasi-inversion of collection and holds between a whole and its uniform unit; for example, *Sing (snow) = snowflake*, *Sing (sand) = grain*; v) a whole and its center or culmination meronym is named *LF Centr*: in contrast with the previous ones, it is a rule used syntagmatically; for example, *Centr (mountain) = the peak*, *Centr (film) = climax*.

4.0 Discussion

So far in this article, we have presented studies originated mainly in logic and linguistics to cope with the multitude of aspects involving part-whole notions. The purpose was not to provide an exhaustive survey, which would not be possible due to the complexity of the subject and the large amount of material available. However, we hope we have presented some of the main aspects and possibilities in the study of part-whole relations.

After having presented two distinguished approaches, it is worth mentioning that some initiatives for studying part-whole relations are neither strictly mereological nor linguistic, but a mix of them. Examples are the often cited works of Gerslt and Pribbenow (1995), which relies on the compositional structure of wholes for distinguishing kinds of relations; and of Iris *et al.* (1988), which uses the relational model of the human semantic memory to reach four kinds of part-whole relations. In addition, there are initiatives that come from fields related to technology that, in the same way, merge more than one perspective. One can find works related to part-whole relations developed in the scope of Knowledge Representation (KR), which include variations of mereology and are ultimately directed towards solving problems of automatic reasoning, like the works of Markowitz *et al.* (1992), and Artale *et al.* (1996). Within KR, there are also other ones applied to specific domains, like Schulz *et al.* (2006) in biomedicine. Still, there are similar works in the scope of other technology-related fields, like Conceptual Modeling. Examples are Storey (1993), Barbier *et al.* (2003), and Guizzardi (2009).

In the beginning of section 2.1, we suggested that formal part-whole relations are based on intuitive notions that people possess. We account for this by citing references that explain the role of part-whole notions in the human conceptual system and human visual perception. However, some mereological properties are targets of criticism. For example, the property of extensionality provided by extensional mereology (section 2.4) asserts that entities are defined by their parts. So, one could say that the words “*no*” and “*on*” are the same one, insofar as both words are composed by the same parts, namely “*o*” and “*n*” (Pribbenow, 2002). Likewise, classical mereology ensures that one can sum arbitrary objects in order to reach a whole. Thus, one might suggest the possibility of summing “*my stomach*”, “*my car*” and “*the warmest corner of my office*” (Jansen, 2008). Moreover, in the

scope of basic mereology (section 2.3), one can find the property of transitivity, by far the most criticized mereological property.

In the remaining part of this section, we focus on discussing the issue of transitivity of part-whole relations because of its importance, which can be justified at least by two main reasons. The first reason is that this issue has been subject to a very long dispute: against approaches that defend the mereological principle of transitivity, some linguistic approaches, which were already presented so far (section 3), claim that many usual situations appear to violate the very same principle. Ultimately, this dispute results in questioning whether there is a single part-whole relation or several of them (some transitive, some not). The second reason is the importance of transitivity for information retrieval in the scope of KOS: transitivity between concepts representing entities allows query expansion, which is made possible by the propagation of properties along a transitive chain (Weller; Stock, 2008).

In the following sections, we firstly explain the issue of transitivity of meronyms as it is posed by non-formal approaches (section 4.1). We show how linguistic initiatives have been, in many cases, attempts to provide answers for cases in which meronyms do not seem to be transitive, as a mereological part-whole seems to be. Then, we present arguments in favor of the transitivity of part-whole relations as proposed by defenders of formal approaches (section 4.2). Finally, we suggest that, considering the inherent difficulties in choosing one or another approach, information scientists could be oriented by pragmatic reasons related to the development of KOS.

4.1 Transitivity of meronymic relations according to non-formal approaches

In the scope of Linguistics, it has been suggested that, in many situations, legitimate senses of the term “*part*” go against transitivity. So, there would be cases of both transitive and non-transitive meronyms. One can find several flavors of this line of thought: some authors believe that there are situations in which meronymic relations are non-transitive (Lyons, 1977; Cruse, 1986); on the contrary, some authors declare that failures in meronymic transitivity are illusory (Croft; Cruse, 2004); some others claim that instead of a single relation, meronyms are actually a family of relations, and that the apparent non-transitivity of it actually involves different types of relations (Winston *et al.*, 1987); likewise, others agree that meronyms represent a

group of relations, some of which are transitive, some of which are not (Iris *et al.*, 1988).

Lyons (1977) starts by emphasizing the difference between, on the one hand, entities of the world itself – separable parts of a thing and the whole thing of which they are parts – and, on the other hand, the vocabulary employed to refer to these entities. Thus, the transitivity of part-whole holds between physical entities. However, it does not hold for all lexical relations used to refer to these entities within the vocabularies of languages. For example, an object A may be referred to as *the handle* and be part of another object B, which may be referred to as *the door*. The object B may also be part of a third object C, which may be referred to as *the house*. Arguably, one can conclude that A is part of C. However, sentences like *the house has a handle* or *there is a handle on this house* are odd; phrases as *the house-handle* or *the handle of the house* seems unacceptable, casting doubts on the transitivity of the relation; otherwise, phrases like *the door-handle* and *the handle of the door*, as well as sentences like *the door has a handle*, are acceptable.

The possibility of identifying both transitive and non-transitive meronymic relations among sentences may be evidence of the existence of more than one type of meronym. Indeed, it is because of transitivity issues that Lyons (1977) points out the existence of two meronymic relations, which we have already presented in section 3.3 (necessary and optional meronyms). We can therefore extend this explanation to transitivity, which gives rise to more than one type of meronymic relation, to other approaches. As we also showed in section 3.3, the approaches of Lyons (1977), Cruse (1986), and Croft and Cruse (2004) can be explained together, since they may be classified as the same type of meronymic relation, named differently though: Cruse's canonical meronym corresponds to Lyons' necessary, and to Croft and Cruse's intrinsic; Cruse's facultative meronym corresponds to Lyons' optional and to Croft and Cruse's extrinsic. Nevertheless, it's worth evaluating the explanations for transitivity provided by Cruse more closely, as well by Croft and Cruse.

Cruse (1986) assigns failures of transitivity in meronyms to two aspects: the notion of *functional domain*, and the difference between two kinds of parts, namely, *attachments*, and *integral parts*.

In order to explain the first aspect – *functional domain* – two sets of sentences are proposed as examples:

(1a) The jacket has sleeves.	(2a) The house has a door.
(1b) The sleeves have cuffs.	(2b) The door has a handle.
(1c) The jacket has cuffs.	(2c) The house has a handle.

In the first set of sentences, (1c) is a valid conclusion from (1a) and (1b). However, considering the second set of sentences, (2c) is not a valid conclusion from (2a) and (2b). This occurs because a part typically has a function with respect to the whole. Thus, in the second example, the functional domain of a *handle* is restricted: a handle serves to open a door, but it does not have any function with respect to something larger (of which the door is part) like a house. On the contrary, in the first example, the functional domain of *cuff* is generalized: the function of a cuff is a decorative one both with respect to sleeves and jackets. If the context is a generalized functional domain, meronyms are transitive; in the case of a restricted functional domain, meronyms are non-transitive.

In order to understand the second aspect – *attachments vs integral parts* – one needs to differentiate these two types of parts. One criterion to do this is to consider that the wholeness of an entity is destroyed if an integral part is missing, but this is not true if the missing part is an attachment. So, it is normal to refer to attachments as being connected to a larger entity, as in the sentence *A handle is attached to a door*, because a *door* does not cease to exist if a *handle* is missing; but it is odd to refer to integral parts in the same way, as in the sentence *The handle is attached to the spoon*, because there is no *spoon* if a *handle* is missing. Thus, meronyms would be transitive only when the parts in the relation are integral parts.

Croft and Cruse (2004) depart from examples provided by Cruse (1986) to suggest that failures in meronymic transitivity are illusory. In order to understand their proposal, one needs to understand the notion of *construal* in the scope of *frame semantics* (Fillmore, 1976). According to the theory of frame semantics, which is a field of study within Cognitive Linguistics, certain concepts are closely tied to other ones because they are associated in the human experience. These concepts are organized in *frames*, which are collections of facts that specify the features of an entity, as well as its typical interactions with other entities necessarily associated with it. For example, a *business transaction frame* is based on recurring experiences of business transactions. How an experience is enclosed in a frame is a matter of a *construal*: it depends on how a speaker conceptualizes the experience to be communicated, for the understanding of a listener.

Croft and Cruse (2004) use Cruse's distinction between integral parts and attachments to argue that meronyms are transitive, but they use another criterion to identify if a part is either an attachment or an integral part. If A is part of B and A is attached to B are both normal, then A is an attachment of B. An example involving attachments between *hand* and *arm* can be seen in the pair of sentences *The hand is part of the arm / The hand is attached to the arm*, because both of them are normal. In this case, the meronym would be non-transitive, insofar as the part *hand* is an attachment in relation to *arm*, not an integral part. However, Croft and Cruse (2004) declare that this example is not a reason for considering that meronyms are non-transitive, because what actually happens is only a difference between construals. In the first sentence of the pair just mentioned, *arm* receives an inclusive construal with respect to *hand*; on the contrary, in the second sentence, *arm* receives a construal that excludes *hand*.

Winston *et al.* (1987) claim that meronyms are transitive relations. Situations in which meronyms seem to be non-transitive actually involve a mix of more than one type of relation. A first set of sentences can be considered as an example:

- (1a) Simpson's finger is part of Simpson's hand.
- (1b) Simpson's hand is part of Simpson's body.
- (1c) Simpson's finger is part of Simpson's body.

In this case, the inference obtained in (1c) is not valid, as well as there is an evident failure of transitivity in (1c). This failure occurs because there is a mix of different types of meronyms: (1c) is a *component-object relation*, while (1b) is a *member-collection relation*. A second set of sentences can be considered as an another example:

- (2a) The refrigerator is part of the kitchen.
- (2b) The kitchen is part of the house.
- (2c) The refrigerator is part of the house.

Again, in (2c) the inference is not valid, and there is a failure of transitivity. This failure is due to the use of a *component-object relation* in (2a) together with a *place-area relation* in (2b). Winston *et al.* (1987) conclude that as long as one keeps a single sense for the term "*part*" in situations like these, the meronymic relation will be transitive. Otherwise, failures of transitivity will arise.

The same line of thought can be used to understand the types of meronyms proposed by Wanner (1996) and by Iris *et al.* (1988): *whole-segment relation* is

transitive (for example, the pairs: *month-day*, and *bread-slice*); the *whole-functional component relations* (for example: *car-engine*, and *door-handle*) and *collection-member relations* (for example: *pride-lion*, and *crew-captain*) are not necessarily transitive.

Finally, it is worth emphasizing that the types of meronyms presented before (section 3.3) are in many cases, as we show so far in this section, originated from the belief that there are both transitive and non-transitive meronyms, and that we should label them differently.

4.2 Transitivity of part-whole relations according to formal approaches

As we have already seen in the last section (section 4.1), there are several proposals that claim the non-transitivity of meronyms, which we could call the linguistic correspondent to the mereological part-whole relation. However, some authors believe that this issue of non-transitivity is not legitimate. In this section, some proposals of this sort are presented (Simons, 1997; Varzi, 2006; Johansson, 2004; Keet; Artale, 2008).

Simons (1987) argues against cases of non-transitivity of part-whole relations provided by linguists, like Cruse (1979); and provided by philosophers, like Rescher (1955). The main example due to Cruse is the one we already cited more than once throughout this paper: *a handle is part of a door, and the door is part of a house, but the handle is not part of the house*. The examples due to Rescher are related to biological units, such as *a nucleus is part of a cell and the cell is part of an organ, but the nucleus is not part of the organ*; and related to institutions, such as *a platoon is part of a company, a company is part of a battalion, but a platoon is not part of a battalion*. These examples are contested firstly through an appeal to our intuition: “if the cell is not part of an organ, is it somewhere outside the organ? [...] Again, if the handle is not part of house, is it lying somewhere detached from the house?” (Simons, 1987, p.107). Simons does not explicitly mention differences in relations between things and relations between lexical items, but he explains what actually happens in these and in other examples: non-transitivity arises when one considers senses that are extrinsic to the part-whole theory, such as a function in both cases of the pairs *handle-house* and *nucleus-cell*. In the case of the pair *platoon-battalion*, the sense which is not transitive is another one and has to do with lines of command in the scope of an institution (the army). Considering only intrinsic aspects of the part-

whole relation, one could comply with the broader sense of the relation, in which the part-whole relation is always transitive.

With respect to the classical example of non-transitivity, the aforementioned case of the *handle-house* pair, Varzi (2006) claims that, on the contrary, a handle has all characteristics of a legitimate part such as: a handle contributes to the mass and to the shape of a house, it occupies part of the whole space occupied by a house, it is destroyed in case the house of which it is part is destroyed, and the destruction of the handle causes changes in the whole house. Thus, the apparent non-transitivity of part-whole would have to do with the existence and application of an invisible predicate modifier, which we represent here by ϕ , to the original part. So, the part-whole relation is transitive, but relations identified by “ ϕ -part-whole” would not necessarily be, exactly because they do not represent the genuine part-whole relation, but another one with a narrowed sense. For example, consider the apparent case of non-transitivity such as: *the arm is part of the musician, the musician is part of the orchestra, but the arm is not part of the orchestra*. Actually, the arm is not *directly* part of the orchestra, but it is directly part of the body and the body is directly part of an orchestra. Also, consider another aforementioned example: *a nucleus is part of a cell and the cell is part of an organ, but the nucleus is not part of the organ*. Again, what happens is that the nucleus is not a *distinguished* part of the organ. However, the nucleus is a distinguished part of the cell, as well as the cell is a distinguished part of the organ.

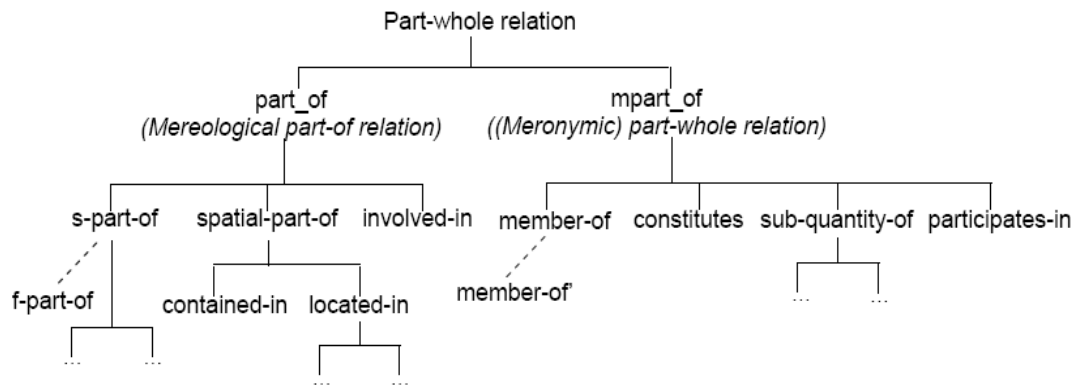
Johansson (2004) explains that part-whole relations are said to be transitive within mereology because, in this context, parts are only considered to be spatial or temporal. Then, one can argue with justice whether the mereological part-whole relation may be just a special case of some broader sort of general part-whole relation. In order to solve this puzzle, one first has to consider, as suggested by Varzi (2006), a predicate modifier ϕ that changes the original meaning of the part-whole relation. In addition to agreeing with the presence of such a predicate modifier, Johansson also reveals the nature of this predicate: it has to do with the the *arity* of the relations under observation. The arity of a relation is the number of elements involved in any instance of that relation: if there are two elements involved, such as x and y , so a relation R is *binary* (Rxy); if there are three elements involved, such as x , y and z , so the relation R is *ternary* ($Rxyz$); and so forth. Mereological part-whole

relations are both binary and transitive relations; meronyms and other similar relations – mereological part-whole relation plus a predicate modifier ϕ – may be neither binary nor transitive.

In order to understand this, one can consider this example: *x can be a large spatial part of y* and *y can be a large spatial part of z*, but yet *x need not necessarily be a large spatial part of z*. The non-transitivity of this example lies in the fact that the relation *is large spatial part of* involves three individual elements, not only two as it may seem. What one needs to realize is that the notion of size embedded in the relation *is spatially large* does not represent a unary predicate, as it seems to be. For example, a real case of a unary predicate, which is related to the notion of roundness of something, is embedded in the relation *is round*. Indeed, both roundness and size inhere in things, but on the contrary of the predicate *round*, the predicate *large* is not unary and does not represent only a size: in addition, it also denotes a relation between a thing to which it is originally attributed and another one, namely a smaller thing. Another example is the relation *is an aunt of*: if *x is aunt of y*, then there exists another entity *z* such that both *x is sibling of z* and *z is parent of y*. Indeed, in situations like these and for many other values of a predicate modifier ϕ , the composition ϕ -part is not a binary relation, but a relation in which at least three relata are involved. In these cases, the mereological properties, like transitivity, cannot be properly considered.

Keet and Artale (2008) propose a taxonomy that encompasses meronym and mereological part-whole relations within a single scheme. The potential differences among part-whole relations and parthood-like relations in the taxonomy are assigned to different sorts of entities used as relatas of the relations. However, the branch of the taxonomy named “meronymic part-whole relation” is symbolized by “*mpart-of*” (see FIGURE 6), in which the letter “*m*” seems to refer to some variation of the predicate modifiers suggested by Varzi (2006), and Johansson (2004). So, also in this proposal, there is no direct comparison involving mereological and meronymic relations.

Figure 6: Taxonomy of part-whole relations



Source: Keet and Artale (2008, p.95)

4.3 Transitivity or non-transitivity in part-whole relations?

The two prior sections (sections 4.1 and 4.2) presented arguments for and against the transitivity of part-whole relations. There are different positions, as one can notice reviewing these two sections. On the one hand, among philosophers interested in mereology there is an almost complete consensus that part-whole relations, that is to say mereological relations, are transitive insofar as the term “*part-whole*” maintains its original sense: they are transitive when the relata are both substantial entities and processual entities (Smith; Munn, 2008); they are transitive if the parts and wholes involved are either spatial or temporal (Johansson, 2004); they are domain-independent as well as isomorphic to the relation of set-inclusion, which is arguably transitive (Varzi, 2006). On the other hand, linguists and other researchers reveal situations in which part-whole relations, that is to say meronymic relations, do not maintain transitivity: transitivity does not hold for all lexical relations used to refer to things (Lyons, 1977); transitivity depends on the context (Croft; Cruse, 2004); meronyms are not always transitive, and the presence of this property depends on the sense assigned to the term part (Winston *et al.*, 1987).

All these arguments sound reasonable and in analyzing them, one still cannot see clearly whether part-whole relations should be considered transitive. We believe that there is no single correct answer for this puzzle, but some considerations are in order.

Firstly, there is some conflict between the needs of a philosopher and the needs of a linguist. The former is concerned with the construction of a logical theory, which demands non-ambiguity, simplicity and logical consistency; the latter deals with the inherent richness of natural languages, which takes into account the

complex features of linguistic usages employed to characterize things. This conflict results ultimately in two interpretations of part-whole relations, which have been extensively mentioned so far in this paper (mereological part-wholes and meronyms). We believe that a researcher should acknowledge these two possibilities, while, at the same time, be attentive to the differences between them. These differences, as we have already seen, are extended to the properties of relations, as illustrated in the case of transitivity.

Secondly, it is noteworthy that authors holding these divergent positions agree at least on one point, which actually rests on the center of the dispute: it is not a trivial task to reach a unique sense for a relation and its properties when, on the one hand, the relata involved are things of the world; and, on the other hand, the relata involved are linguistic units used to refer to these things (Varzi, 2009; Lyons, 1977). So, generally speaking, one could pose the question whether relations would be considered to hold among things or to hold among the means we use to refer to these very same things. Within the realm of Information Science, where information retrieval from documents is a seminal issue, this question could be rephrased as: when establishing relations, should one be concerned directly with the things of reality or should one be concerned with the representation of these things in the content of documents? Indeed, the content of a document is *about* the reality. This question can lead one to investigate the concept of *aboutness*, which is a very dear concept within Information Science. A detailed explanation of this topic is beyond the goals of this paper and one interested can find several sound references, like Hutchings (1978), Beghtol (1986), and Hjørland (2001), to mention but a few.

So, we limit ourselves here to suggest what seems to be clear: in order to establish relations for the purposes of information retrieval, one should consider the richness of natural languages because documents are written using such languages. Nevertheless, it would be useful to take into consideration, as a first step, the support of more controlled frameworks. What we are saying is that in reasoning about relations among plain entities (spatial and temporal), and understanding as relations hold among these entities, one can obtain the support to face more intricate situations posed by the complexities of natural languages. Actually, this sort of idea is not a novelty: in the scope of Linguistics, it is usual that developments made firstly in Formal Semantics, which succeed in a controlled scenario, can be then tried in natural language, in a real-world scenario.

Finally, we propose that in adopting a pragmatic-oriented approach, which focuses ultimately on the development of KOS, one can reach a sort of criterion to choose whether a specific part-whole relation would be considered transitive. In order to better understand this, we briefly examine some typical characteristics of both thesauri and ontologies, two kinds of KOS currently widely used for information retrieval.

In the development of thesauri, there is no mandatory need to be so accurate in the definition of relations. A developer can employ the *broader-than* relation and the *narrower-than* relation, which are used to define the taxonomy backbone of the vocabulary. In addition, there is the *related-term* relation, in which more than one type of relation is gathered together. These relations are usually found in a typical thesaurus like, for example, the *Medical Subject Headings* (MeSH). MeSH is a controlled vocabulary created by the *National Library of Medicine of the U.S.A.*, which is used to index, catalogue and search for biomedical information. Examples of real relationships one can find in MeSH are: *Fetal_Blood narrower-than Blood*, and *Plasma narrower-than Blood* (Schulz *et al.*, 2009).

From the point of view of information retrieval, these relations meet the needs of indexing and retrieving documents, insofar as scientific papers on *blood_plasma* are pertinent to a query on “*blood*” as are papers on *fetal_blood*. However, from an ontological point of view, this example actually contains two distinguished relations: *plasma part-of blood* denotes a part-whole relation, and *fetal_blood is-a blood* denotes a type-subtype relation. So, if the KOS under construction is an ontology, there is a need for more precision in defining relations, to the extent that ontologies are instruments created to be manipulated by computers. Ultimately, the definition of a well-understood interpretation for relations is particularly important if query expansion to be automated.

Thus, as one can notice, the kind of KOS under construction provides an indicative of the kind of relation, more or less formal, that would be adopted. Likewise, it provides our aforementioned criterion to determine whether the part-whole relation under observation should be considered transitive. So, in the development of an ontology, in which it is possible to put axioms of mereology to restrain the meaning of the term “*part*”, transitivity can be considered. In the development of a thesaurus, the transitivity of part-whole relations cannot be considered *a priori*. However, in practical terms, it is not clear if one approach would

be better than another. On the one hand, one could claim that, if an instrument can always rely on transitivity, there is a real advantage because it can reach better results with the query expansion through the transitive chain. On the other hand, one could claim that the effort consumed to formalize relations in an ontology cannot provide valuable improvements for information retrieval, or it can even make such retrieval more difficult.

Even considering differences in properties like transitivity, formal and non-formal approaches do not necessarily exclude each other. Both instruments, thesauri and ontologies, have been employed for information retrieval. The construction of thesauri, which is a traditional instrument for information retrieval, is a highly surveyed topic in the scope of Information Science (ANSI, 2005). With respect to ontologies, there are a growing number of proposals suggesting that their use would be a still more efficient and advantageous method for information retrieval. Some claims in favor of ontologies are generic, only focusing on the increasing importance of computers. But, there are also real examples of applications of ontologies, along with thesauri or not, in information retrieval. We can briefly describe only a few, as illustrative examples.

Bechhofer and Goble (2001) have proposed, since some years ago, to integrate thesauri and description logics – the latter, a currently very popular scheme to build ontologies (Baader *et al.*, 2010) – with the aim to support navigation, query expansion, and similarity-based searching capabilities. Furthermore, this scheme allows automatic classification, then assisting the construction and maintenance of large thesauri. Müller *et al.* (2004), for example, propose the use of ontologies for information retrieval from documents, while focusing on knowledge classification techniques. Giunchiglia *et al.* (2013), in the scope of a traditional Information Science event, present a proposal inspired in the faceted approach (Broughton, 2006), in which the properties of entities described in documents are formally defined using ontologies, as a way to better retrieve them. This latter is an example of an approach in which the queries are directed to the properties of the entities described in a document.

Still, noteworthy is the emergence of events, which are sponsored by traditional organizations in the field of Information Science, emphasizing aspects of ontological analysis or formal ontology modeling in the realm of knowledge classifications (Slavic; Civallero, 2011). Indeed, this sort of interplay between

research fields is not so different from the interdisciplinary studies foreseen by Vickery still in the 1990s, for whom “the problems with which information scientists have for so long been struggling, are now faced by a wider community of knowledge engineers” (Vickery, 1997, p. 285).

5.0 Final remarks and conclusion

In this paper, we investigated two perspectives used to explain the notion of parts and wholes. The first, we called formal, is mainly based on the philosophical studies of mereology; the second, we called non-formal, is mainly based on linguistic studies and related fields like cognitive linguistics. We studied the main characteristics of two types of relations that represent the notion of parts and wholes, namely, the mereological part-whole relation and the meronymic relation. In order to provide a discussion involving both approaches, we elect to elaborate on transitivity, which is an important property of the part-whole relation for purposes of information retrieval. In the final part of our discussion, we proposed that one should adopt a pragmatic criterion in order to choose the better approach.

This criterion seems merely to indicate that one should adopt a formal approach when constructing ontologies, and a non-formal approach when constructing thesauri. However, one can notice that neither the relation between mereology and meronym nor the relation between thesauri and ontologies are so straightforward.

Firstly, with respect to relation between mereology and meronym, the characterization of transitivity shows that formal and non-formal approaches are distinguished, but somehow complementary. Indeed, transitivity is the property that most clearly reveals such complementarity, since some non-formal approaches are attempts to find answers to criticisms aimed at formal approaches, which do not fit totally with the rich realm of natural languages. As we showed before (section 4), these criticisms generate replies from philosophers and mereologists with interesting results. Some authors could prove that two potential part-whole relations under observation actually are not even the same relation. In this context, one may be comparing a part-whole to a part-whole plus a modifier (Varzi, 2006). Also, different varieties of relations, at first glance considered as part-whole relations, show the variations concealed in the richness of the linguistic usages (Johansson, 2004). Finally, what seems to be the most concrete result of this controversy is to

acknowledge that there is no good answer for the dispute. It is a very demanding task to find a single, uniform sense of the term “*part*”.

Secondly, with respect to relation between thesauri and ontologies, there are differences between the purposes of each of these structures, but also similarities: both of them provide the possibility of constraining natural languages (Gilchrist, 2003), even though these constraints occur in different levels of formality. In favor of ontologies, there are growing claims suggesting the need for new requirements for the standardization of terminology, which must go beyond the needs of humans in order to better serve the very same humans through automatic systems. The need of computer-processable representations would become urgent with the enormous increase in the amounts and varieties of data with which researchers are usually faced, data which can no longer be surveyed without the aid of computers and systems. In this context, formal approaches would be preferred (Rector, 1999; Smith, 2008). We believe that a proper answer for this question about the usage of ontologies or thesauri will only be provided by empirical research.

Ontologies are most of the time associated only with computational approaches. Indeed, when the term “ontology” became popular in the 1990s, it was interpreted at first as a new catchword for knowledge representation artifacts in the scope of expert systems. However, two related branches have evolved since then: on the one hand, there is the vision of the Semantic Web initiative, which really focuses on computational systems based on a decidable fragment of the first-order logic that makes possible automatic inferences in the web (Berners-Lee *et al.*, 2001); on the other hand, the discipline of philosophical ontology was combined with requirements of modern information society, creating a discipline so-called applied ontology (Guarino, 1998; Smith, 2004). We believe this discipline has much to do with Information Science theories, when dealing for example with classifications, thus becoming a genuine and fruitful subject of research in Information Science (Almeida, 2013). We intend to continue exploring this subject in future papers.

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