COGNITIVE SCIENCE **11**, 417–444 (1987)

A Taxonomy of Part-Whole Relations

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A taxonomy of part-whole or meronymic relations is developed to explain the ordinary English-speaker's use of the term "part of" and its cognates. The resulting classification yields six types of meronymic relations: 1. component-integral object (pedal-bike), 2. member-collection (ship-fleet), 3. portion-mass (slice-pie), 4. stuff-object (steel-car), 5. feature-activity (paying-shopping), and 6. place-area (Everglades-Florida). Meronymic relations are further distinguished from other inclusion relations, such as spatial inclusion, and class inclusion, and from several other semantic relations: attribution, attachment, and ownership. This taxonomy is then used to explain cases of apparent intransitivity in merological syllogisms, and standard form syllogisms whose premises express different inclusion relations. The data suggest that intransitivities arise due to equivocations between different types of semantic relations. These results are then explained by means of the relation element theory which accounts for the character and behavior of semantic relations in terms of more primitive relational elements. The inferential phenomena observed are then explained by means of a single principle of element matching.

1. INTRODUCTION

Much recent work in linguistics, logic, and cognitive psychology has focussed on understanding the nature of semantic relations. One important type of semantic relation is the relation between the parts of things and the wholes which they comprise. While knowledge of parts and wholes can be expressed

The authors thank the students of Trenton State College who assisted in this work, particularly Donna Transue and Ann Adam. We also thank Mary Crawford, Robert DiPietro, Charles Goldberg, LaVerne Shelton, and an anonymous reviewer for helpful comments on earlier versions of the paper. The research was supported in part by the Trenton State College Institutional Research and Sabbatical Leave Fund, by The Center for the Study of Values of the University of Delaware, and by NIMH grant #1-R03-MH3656601 and a postdoctoral fellowship from the Educational Testing Service to the second author.

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in many specialized ways, we will focus on the relation expressed by the English term "part of," as in, "The X is part of the Y," "X is partly Y," "X's are part of Y's," "X is a part of Y," "The parts of a Y include the Xs, the Zs...," and similar expressions, such as in the sentences: "The head is part of the body;" "Bicycles are partly aluminum;" "Pistons are parts of engines;" "Dating is a part of adolescence;" "The parts of a flower include the stamen, the petals, etc. ..." We will refer to relationships that can be expressed with the term "part" in the above frames as "meronymic" relations after the Greek "meros" for part.[1]

From a logical point of view, meronymic relations are usually understood to express strict partial ordering relations. Strict partial ordering relationships are transitive, irreflexive, and antisymmetrical (Halmos, 1960; Moore, 1967), that is, if P is the relation expressed by the English phrase "is a part of," then, if aPb, and bPc, then aPc (transitivity); -aPa (irreflectiveness); and -bPa (antisymmetry). These logical properties of meronymic relations make them particularly important to our understanding of the structure of the lexicon since, as a partial ordering relation, like class inclusion, meronymic relationships structure semantic space in a hierarchical fashion.

There are, however, important questions about meronymic relations which need to be answered. Are there several distinct families of meronymic relations or only one general type? How are meronymic relations to be distinguished from other semantic relations? And, are meronymic relations always transitive?

In order to answer these questions, we have developed a taxonomy of the kinds of semantic relations that are expressed by the ordinary English speaker's use of the phrase "is a part of" and its cognates. A further goal of this study is to try to understand the implications of meronymic relations for current theories of semantic memory. Current theories of the structure of the lexicon generally assume that knowledge of semantic relations is stored in semantic memory in a structured and interrelated fashion. This structure has been conceptualized variously in terms of prototypes, networks, or frames (Anderson, 1976; Norman, Rumelhart, & the LNR Research Group, 1975; Rosch & Mervis, 1975; Schank & Abelson, 1976). While all of these accounts assume that relations between concepts in memory are central to

[1] Cruse (1986) proposes a two-part linguistic test for isolating meronyms: "X is a meronym of Y if and only if sentences of the form *A Y has Xs/an X* and *An X is part of a Y* are normal when the noun phrases an X, a Y are interpreted generically." He notes, however, that "this definition is undoubtedly too restrictive, in that it excludes some intuitively clear examples of the part-whole relation, but [it] characterizes what we shall take to be the central variety of the lexical relation." (Cruse, 1986, p. 160) We agree that this two-part test is too restrictive and therefore propose this less restrictive criterion for identifying meronymic relations. Cruse's use of the more restrictive test leads him to characterize certain relations which we regard as types of meronymy as non-meronymnic or quasi-meronymic relations. We will, however, follow Cruse's spelling of "meronymy" and also his use of the term "meronym" to refer to the part-term of a meronymic relation; the term for the whole will be called a "holonym."

the way that semantic knowledge is represented, relatively little attention has been paid to the question of precisely which semantic relations are represented, and how they are to be distinguished from one another (Chaffin & Herrmann, 1984).

Often meronymy has not been clearly distinguished from other semantic relations. Psychological studies of class inclusion decisions have often included part-whole relations as examples of class inclusion (e.g., Battig & Montague, 1969; Loftus & Scheff, 1971; Smith, Shoben, & Rips, 1974). Prototype theory (Rosch & Mervis, 1975) explains conceptual structure in terms of category relations and groups all other relations together as "attributes" of concepts, a term which covers at least parts (*handle-cup*) and functions (*drink-cup*) (Tversky & Hemenway, 1984). Network models of memory have frequently confused meronymy (*wing-canary*) with other relations such as attribution (*yellow-canary*); for example, (Collins & Quillian, 1969). One goal of the present inquiry was to distinguish meronymy from other similar relations, such as possession, attribution, and class inclusion.

Even when meronymy has been distinguished from other relations a comprehensive account of it has not been developed (Evens, Litowitz, Markowitz, Smith, & Werner, 1980). One reason may be that there are several distinct meronymic relations, each with different semantic properties. This conclusion has been suggested by researchers in psychology (Markman, 1982), linguistics (Apreysan, Mel'cuk, & Zolkovsky, 1970; Iris, Litowitz, & Evens, 1986; Lyons, 1977), and philosophy (Nagel, 1961; Sharvy, 1980, 1983; Smith & Mulligan, 1982). Markman (1982) studied the development of children's understanding of the collection-member (*tree-forest*) relation and distinguished this relation from relations like *leaf-tree*. Lyons (1977, pp. 331–317) suggested that there is a variety of part-whole relations; he distinguished singular collections, (*the herd is*) from plural collections, (*the players are*), and contingent (*door-house*) from necessary part-whole relations (*minute-hour*). Nagel (1961), in an analysis of the problem of reductionism, distinguished eight major types of wholes which differ in their relation to their parts. While these studies provide insights into the variety of meronymic relations, none provides, in our opinion, a comprehensive account of that variety and none has been specifically concerned with the implications of this variety for theories of lexical structure and inferences involving meronymic relationships.

In this paper, we describe criteria for distinguishing among various kinds of semantic relations, and apply them to the analysis of meronymic relations. Our taxonomy recognizes linguistic and logical differences among various meronymic relations. It supports the view that meronymy is a transitive relation, and accounts for cases of apparent intransitivity by showing that they involve equivocations between different kinds of meronymic relations. In conclusion, we discuss our taxonomy of meronymic relations in terms of a more general theory of semantic relations, relation element theory, and

draw out the consequences of this view of semantic relations for current theories of semantic memory and the structure of the lexicon.

2. TOWARD A TAXONOMY OF MERONYMIC RELATIONS

The main reason for thinking that there are distinct types of meronymic relations, and that meronymic relations are distinct from other sorts of semantic relations, derives from what we term the "common argument" criterion. One way to determine that two semantic relations are different is to find a case in which both apply to the same subject, but answer different questions about it. For example, an oriole is a type of bird (class inclusion), has wings (meronymy), and is brightly colored (attribution). When predicates of different types can all apply to a single subject we say that there is a "common argument." Thus, for example, "bicycle" is the common argument of the sentences "Bicycles have wheels," and "Bicycles are made of aluminum." In this case, these relationships can also be expressed using the term "part," for example, "Wheels are parts of bicycles." and "Bicycles are partly aluminimum." Each of these statements adds information of a new type about the common subject, bicycles.

The common argument criterion thus supports a distinction among at least two types of meronymic relationships: component-object (*pedal-bicycle*), and stuff-object (*aluminum-bicycle*). However, this division only works well with respect to solid, physical objects, or extensive wholes. The classification of part-whole relationships must also take account of the uses of "part" with respect to collections, masses, activities, and areas. We distinguish six major types of meronymic relations that can be expressed by the term "part" and its cognates: 1. component-integral object (pedal-bike), 2. member-collection (ship-fleet), 3. portion-mass (slice-pie), 4. stuff-object (steel-car), 5. feature-activity (paying-shopping), and 6. place-area (Everglades-Florida). The taxonomy is summarized in Table 1.

The differences among the six types of meronymic relations are indicated by the values of three relation elements which summarize characteristic properties of the relations. Meronymic relations differ in three main ways: whether the relation of part to the whole is functional or not, whether the parts are homeomerous or not, and whether the part and whole are separable or not. Functional parts are restricted, by their function, in their spatial or temporal location. For example, the handle of a cup can only be placed in a limited number of positions if it is to function as a handle. Homeomerous parts are the same kind of thing as their wholes, for example, (*slice-pie*), while nonhomeomerous parts are different from their wholes, for example, (*tree-forest*). Separable parts can, in principle, be separated from the whole, for example, (*handle-cup*), while inseparable parts cannot, for example (*steel-bike*). We will describe further linguistic and logical differences among the six kinds of meronymic relations and then show how these distinctions resolve the problem of the transitivity of meronymic relations.

TABLE 1
Six Types of Meronymic Relations with Relation Elements

Relation	Examples	Relation Elements		
		Functional	Homeomerous	Separable
Component/ Integral Object	handle-cup punchline-joke	+	−	+
Member/ Collection	tree-forest card-deck	−	−	+
Portion/Mass	slice-pie grain-salt	−	+	+
Stuff/Object	gin-martini steel-bike	−	−	−
Feature/Activity	paying-shopping dating-adolescence	+	−	−
Place/Area	Everglades-Florida oasis-desert	−	+	−

Functional (+)/Nonfunctional (−): Parts are/are not in a specific spatial/temporal position with respect to each other which supports their functional role with respect to the whole.

Homeomerous (+)/Nonhomeomerous (−): Parts are similar/dissimilar to each other and to the whole to which they belong.

Separable (+)/Inseparable (−): Parts can/cannot be physically disconnected, in principle, from the whole to which they are connected.

2.1 Component-Integral Object

The meronymic relation that springs most readily to mind is that between components and the objects to which they belong as in,

(1a) A handle is part of a cup.
(1b) Wheels are parts of cars.
(1c) The refrigerator is part of the kitchen.[2]
(1d) Chapters are parts of books.

[2] Cruse (1986) follows Lyons (1977) in distinguishing between optional and necessary parts, though Cruse prefers the terms "facultative" and "canonical" parts/whole. It is normal for fingers to be part of hands, but it is possible to have a hand which is missing some fingers. Thus, fingers are not logically necessary parts of hands, but canonical parts of them since they are normally parts of them and their absence indicates a defect in the whole. Similarly, it is possible for a kitchen to lack a refrigerator, though in this case it is not clear that that would be a defect, and thus refrigerators are optional or "facultative" parts of kitchens. Kitchens are also facultative holonyms of refrigerators since refrigerators can be found elsewhere than in kitchens. This distinction is bound up with the distinction between specific and generic senses: while it may be false to say generically that "Refrigerators are parts of kitchens," it may be true to say that a particular refrigerator is part of a particular kitchen. Thus, when dealing with a facultative meronym or holonym it is necessary to interpret the noun phrase as referring to a specific case. Since sentences such as (1c) clearly express a meronymic relation, it seems that Cruse's requirement that the generic be used is too restrictive.

(1e) A punchline is part of a joke.
(1f) Belgium is part of NATO.
(1g) Phonology is part of linguistics.

In each of these cases, a particular kind of whole, what we call an "integral object," is divided into components. Integral objects all exhibit some kind of patterned organization or structure. Their components are also patterned and usually bear specific structural and functional relationships to one another and to the wholes which they compose. These structural relations define the particular natures of integral wholes and their components—components cannot be haphazardly arranged but must be arranged in a particular patterned organization within the wholes which they comprise.

Included in this category are some rather specialized senses of "part" as when we speak of "the viola part" in a symphony, or a "part" in a play. Since plays and symphonies are patterned organizations whose natures are defined by their structures, we also call such "parts" components. Objects which can have components, in this sense, may be either concrete physical objects (cups), assemblies (bicycles), representational objects (books, plays, symphonies), abstract objects (linguistics, meanings), organizations (IBM, NATO) or the components of each of these types of things. The heterogeneity of patterned objects suggests that there may be subtypes of this relationship.

One main difference among integral objects concerns whether they are extensive or not (Smith & Mulligan, 1982, p. 17). Physical objects are "extensive" in the sense that they occupy a volume of space and their components are included in the spatial volumes occupied by their wholes. The parts of abstract objects (e.g., linguistics) and organizations (e.g., NATO) are not extensively included in their wholes, but "belong" to them in a nonphysical sense. We group such wholes along with physical objects and assemblies because of their patterned structures or organizations.

Among extensive wholes, that is, physical objects, we can distinguish "components" from "pieces." As Cruse notes (1986, p. 157ff.), if we take a hacksaw and cut up a typewriter, the resulting portions cannot properly be called "parts" of a typewriter (generic), but are better termed "pieces" of a typewriter (specific). Unlike components, pieces lack a determinate functional relation to their wholes, and, as Cruse notes, typically have arbitrary boundaries.[3] Pieces of objects are thus distinct from their components, and "pieces" belong to a different family of meronymic relations that we call the portion-mass relation (see Section 2.3).

[3] In addition, Cruse notes that pieces must be "autonomous" and explains this as follows: "Something described as 'a piece of an X' must once have formed an integral constituent of a properly constituted X." (Cruse, 1986, p. 159) This ancestral relation is not required for components, since, "the items in a display cabinet labelled 'The parts of a typewriter' need never have belonged to the same, or, indeed, any actual typewriter; furthermore, exact copies would count equally well as parts."

2.2 Member-Collection

Membership in a collection differs from componenthood in not requiring that members perform a particular function or possess a particular structural arrangement in relation to each other and to their wholes, as in,

(2a) A tree is part of a forest.
(2b) A juror is part of a jury.
(2c) This ship is part of a fleet.

Collections must be distinguished from classes. The class-member relation is not a meronymic relation because it is not expressed by "part" but by "is," as in,

(2d) The Nile is a river.
(2e) Fido is a dog.

Classes differ from collections in that membership in a class is determined on the basis of similarity to other members, while membership in a collection is determined on the basis of spatial proximity or by social connection. For example, to be part of a forest a tree must be spatially close to the other trees (Markman, 1982). Collections whose members are determined by social connection are generally referred to as "groups." The special properties of classes which distinguish them from collections and groups are described further in the discussion of the class inclusion relation (Section 3.2).

2.3 Portion-Mass

Portions of masses, extensive objects, and physical dimensions are different from components of objects and members of collections in being "homeomerous," that is, having parts which are similar to each other and to the wholes which they comprise, as in,

(3a) This slice is part of a pie.
(3b) A yard is part of a mile.
(3c) This hunk is part of my clay.

Every portion of a pie is "pie" and is similar to each other slice and to the whole pie. Components and members, in contrast, may be dissimilar to each other and different from the wholes which they comprise; for example, a window is not like the house of which it is a part nor is it like the other components of houses, and a tree is not like a forest nor is it "forest."

The portion-mass sense has been distinguished from other senses of "part of" by Sharvy (1980, 1983). He suggests that mass and count senses of "part of" can be distinguished by attempting to replace "part of" with "some of." When "part of" is being used in the mass-portion sense, as in,

(3d) She asked me for part of my orange.

We can readily substitute "some of" while preserving meaning:

(3e) She asked me for some of my orange.

However, when "part of" is being used in the component-integral object sense, as in,

(3f) The engine is part of the car.

we get,

*(3g) The engine is some of the car.

Of course we can interpret (3g) to mean that some of the weight or mass of the car is the weight or mass of the engine. This reading shows, however, that in substituting "some of" we have shifted the meaning to a portion-mass sense of "part" and are referring to a portion of the mass of the car, not to one of its components.

The "some of" test does not, however, serve to distinguish the mass-portion sense of "part" from the collection-member sense, since we can also employ "some" to denote members of a collection, as in,

(3h) Some of the fraternity brothers are sophomores.

This is the count sense of "some" as contrasted with the mass sense of "some" as in "some orange" or "some water." The portion-mass relation can be distinguished from the member-collection relation because members of a collection, unlike portions of masses, can be readily individuated, and so can be designated by "one of," as in,

(3i) One of the brothers is a sophomore.

Portions of masses can also be individuated, but not without employing some unit of measure, for instance,

(3j) Give me a glass of water.

or,

(3k) Give me two beers.

which is elliptical for "Give me two (glasses, mugs, bottles, etc.) of beer." English abounds with specialized measure terms such as "lump," "slice," "drop," "helping," "segment," and so forth, which can be applied to various kinds of portions.

As noted earlier, when a component or integral object is destroyed, we speak of its "pieces." Pieces are like portions of masses in having arbitrary boundaries and in lacking a functional relation to their whole. They are unlike mass-portions, however, in not always being homeomerous—while the pieces of a shattered windshield are "glass," the pieces of an exploded typewriter are not "typewriter."

Because the portions of masses are arbitrary, we can divide and apportion masses by means of standard measures such as inches, ounces, gallons, hours, and so forth. The portion-mass relation thus forms the basis for the arithmetic operations of addition, subtraction, multiplication, and division (Liu, Wang, & Zhang, 1984; Behr et al., 1986).

2.4 Stuff-Object

The stuff relation is a type of meronymic relation which is most often expressed using the "is partly" frame, as in,

(4a) A martini is partly alcohol.
(4b) The bike is partly steel.
(4c) Water is partly hydrogen.

The stuff-object relation is readily distinguished from the component-object relation by the common argument criterion. For integral objects, like bikes, the same argument can occur in an component-integral object relation (e.g., wheel-bike), answering the question, "What are its parts?", and in an stuff-object relation (e.g., bike-steel), answering the question, "What is it made of?." Unlike components, the stuff of which a thing is made cannot be separated from the object, though, of course, the same type of object can sometimes be made of different stuffs.

We include the stuff-object relation as a meronymic relation because it answers a question about the constituency of things and is expressed by the "is partly" frame. This frame expresses the idea that a particular type of substance constitutes a portion of the total stuff of which something is made. When something is made of a single stuff "is partly" cannot be used. Instead the relation must be expressed by "made of," as in,

(4d) The lens is made of glass
*(4e) The lens is partly glass.

In complex objects it is sometimes difficult to distinguish parts, in the sense of stuffs of which things are made, from their components. For instance, when we have a heterogeneous mixture like salad, is tomato a component of the salad, or one of the stuffs of which it is made? Our analysis suggests that the stuff of which a thing is made cannot be physically separated from an object without altering its identity, whereas a component can. A bike without wheels is still a bike, but water without hydrogen is not water. Since it is possible to remove the tomato from a salad, tomato is an ingredient (or component) of salad, not one of its stuffs.[4]

[4] Cruse distinguishes 'ingredients' from 'constituents': "the ingredients of X are the substances that one starts out with when one prepares X, whereas the constituents of X are the substances which enter into the final composition. . . . Thus, although alcohol is a constituent of wine, it is not an ingredient, because it is not used in preparation, but arises naturally as a result of preparation" (Cruse, 1986, p. 177). In terms of our taxonomy, ingredients are kinds of components, while constituents are stuffs.

2.5 Feature-Activity

The existence of a fifth type of meronymic relation is indicated by the use of "part" to designate the features or phases of activities and processes, as in,

(5a) Paying is part of shopping.
(5b) Bidding is part of playing bridge.
(5c) Ovulation is part of the menstrual cycle.
(5d) Dating is part of adolescence.

Unlike the types of meronymy discussed thus far, the feature-activity relation cannot be expressed in sentences of the type "X has Y," and similar locutions (Cruse, 1986, pp. 160–165), such as,

(5e) Sororities have members.
(5f) Bicycles have pedals.
(5g) Plays have acts.
*(5h) Shopping has paying.

Apart from this difference, the activity-stage relationship is like the integral object-component relationship in that complex activities are structured by means of "scripts" which assign locations to particular subactivities or features (Shank & Abelson, 1976), just as integral objects are made up of components. When used in relation to complex or "scripted" activities or events, the term "part" can be used to refer to stages, phases, discrete periods, or subactivities which are included in the "script." When we move from speaking of generic kinds of activities to describing specific events, for example, "war" to "World War II," we use this same meronymic relation.

2.6 Place-Area

A sixth type of meronymy is the relation between areas and special places and locations within them, as in,

(6a) The Everglades are part of Florida.
(6b) An oasis is a part of a desert.
(6c) The baseline is part of a tennis court.

Like the members of collections, places are not parts by virtue of any functional contribution to the whole. Like the mass-portion relation, the area-place relation is homeomerous; every place within an area is similar to every other and to the whole area in that all are areas. Unlike portions of masses, however, places cannot be separated from the areas of which they are a part. Once again, this relationship differs from the other basic types of meronymy, though it does give one kind of answer to the question "What are its parts?"

3. NON-MERONYMIC RELATIONS

Part of the problem of understanding meronymic relations derives from the fact that meronymy is easily confused with other semantic relations, partic-

ularly, other inclusion relations, such as class inclusion and spatial inclusion, and other relations involving possession, such as attachment, attribution and ownership. We will distinguish meronymy from these other semantic relations.

3.1 Topological Inclusion

A relation which may be confused with meronymy is the topological relation between a container, area, or temporal duration and that which is contained in it, as in,

(7a) The wine is in the cooler.
(7b) The prisoner is in the cell.
(7c) West Berlin is in East Germany.
(7d) The meeting is in the morning.

We will focus our discussion on spatial inclusion. In cases of spatial inclusion, the subject is surrounded but is not a part of the thing which surrounds it. Meronymy also normally involves this element of spatial inclusion, for example, the heart is surrounded by the body, but meronymy also involves the additional element of a connection between part and whole. The contrast between spatial inclusion and meronymy is sharpest in the case of the place-area relation which is easily confused with spatial inclusion, as in,

(6a) The Everglades are part of Florida.

The Everglades are surrounded by Florida, just as West Berlin is surrounded by East Germany. But, the Everglades are also part of Florida because, in addition to being spatially included, there is a connection between the two. They are co-extensive in the sense that the Everglades overlap Florida: that is, every part of the Everglades is also "Florida." West Berlin and East Germany, in contrast, are not coextensive: no part of West Berlin is East Germany. The latter relation is simply spatial inclusion and not meronymy.

3.2 Class Inclusion

Class inclusion or hyponymy is usually expressed in the frames, "Xs are type of Y," "Xs are Ys," "X is a kind of Y," and "X is a Y." (Cruse, 1986, p. 89; Lyons, 1977, p. 292; Miller & Johnson-Laird, 1976, p. 241) as in,

(8a) Cars are a type of vehicle.
(8b) Roses are flowers.
(8c) Theft is a crime.
(8d) Fear is an emotion.

Class inclusion and meronymy are clearly distinguished when expressed by "kind of" and "part of." There is no temptation to say "A robin is part of a bird" or "A wheel is a kind of car."

Despite this, class inclusion and meronymy are often confused (Herrmann, Chaffin, & Winston, 1986). The confusion is more acute for some

meronymic relations than others. Class inclusion and meronymy are most difficult to distinguish in the case of activities and abstract nouns which can be ambiguous as to whether they are to be taken as expressing class inclusion or meronymy (Lyons, 1977, p. 314–316), as in,

(9a) Frying is part of/a type of cooking.
(9b) Honesty is part of/a type of virtue.

Class inclusion is also easily confused with the member-collection relation (Herrmann et al., 1986). This is because of the similarity, noted earlier, of the member-class and member-collection relations. Both involve membership of individuals in a larger set, but membership in a collection is determined by spatial or temporal proximity or by a social connection (e.g., tree-forest, cow-herd), characteristics which are extrinsic to the individual members themselves. Membership in a class, in contrast, is determined by similarity to the other members on one or more intrinsic property. Wierzbicka (1984) distinguishes taxonomic classes (e.g., bird, flower) based on overall physical similarity, functional classes (e.g., toy, weapon) based on similarity of function, and heterogeneous classes (e.g., vegetable, medicine) based on similarity of function and origin. Wierzbicka also identifies two kinds of collections, singularia tantum (e.g., furniture, clothing) and pluralia tantum (e.g., leftovers, groceries) in which different kinds of things are used together for the same purpose. These are on the fuzzy boundary between classes and collections involving both similarity and spatial proximity. As a result we can say that, for example, a chair is both a kind of furniture (class inclusion) and an item of furniture (member-collection).

The common element of membership and class inclusion is captured in Euler circles which represent membership by reducing both to a third kind of inclusion, spatial inclusion (Miller & Johnson-Laird, 1976, p. 241). All three relations have inclusion in common. The difference is in the criterion for inclusion—topological encirclement, membership based on joining or proximity, or the required kind of similarity.

3.3 Attribution

A third relation with which meronymy may be confused is the relation of object and attribute, as in,

(10a) Towers are tall.
(10b) Coal burns.
(10c) The joke was funny.

When subjects are asked to list properties of objects they give both attributes of this kind and parts (Ashcraft, 1978; Tversky & Hemenway, 1984). For this reason attribution and meronymy have sometimes been treated as a single relation (e.g., Collins & Quillian, 1969). However, despite their super-

ficial similarity, attribution and meronymy are different relationships. While towers have height as one of their attributes, height is not a part of a tower.

3.4 Attachment

Pairs such as *ear-earring*, *chimney-TV antenna*, and *fishing line-hook* which express the relation of attachment can be confused with meronymy, for example,

(11a) Earrings are attached to ears.
(11b) Fingers are attached to hands.

Fingers are attached to hands, but they are also parts of hands; while earrings are attached to ears, but are not parts of ears. The confusion of the attachment relation with genuine meronymy may be responsible for some of the failures of transitivity in inferences involving part-whole relations (Cruse, 1979; see below Section 5).

3.5 Ownership

Finally, meronymy can be confused with the ownership relation as in,

(12a) A millionaire has money.
(12b) The author has the copyright.
(12c) Jenny has a bicycle.

Meronymy can also frequently be expressed in the "has a" frame,

(12d) A bicycle has wheels.

But, in (12a-c) the "has" is the has of ownership, while in (12d) the "has" is really elliptical for "has as a part."

Figure 1 summarizes our suggested classification of semantic relations.

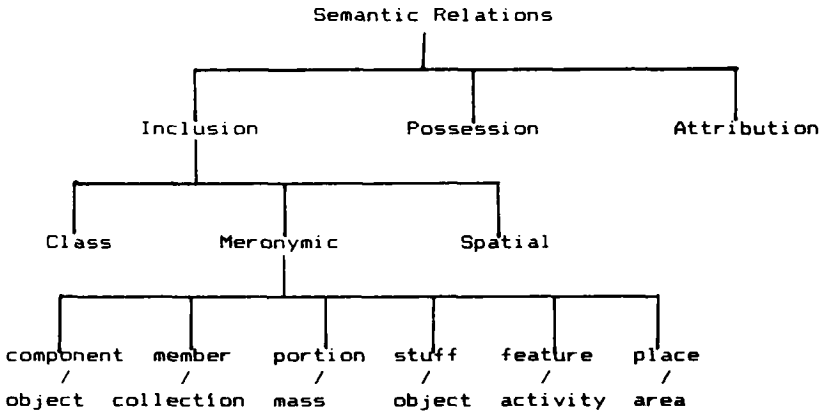

Figure 1. Partial Classification of Semantic Relations

4. THE VAGUENESS OF "PART" AND THE AMBIGUITY OF MERONYM PAIRS

In reviewing the above relations we have observed that surface lexical features of English are not the best guide to the differences among these semantic relations (Wierzbicka, 1984). The term "part" is used to express a variety of quite distinct semantic relations. The vagueness and generality of the term "part" makes it very easy for speakers of English to slip back and forth between types of meronymic relationships and this semantic slippage is, we will argue shortly, responsible for many cases in which meronymy appears to be intransitive.

"Part" is only the most general of a large number of English terms which can be used to express various kinds of meronymic relations. We have made use of some of these in naming types of meronymic relations. Parts of integral objects tend to be called "components"; collections and groups have "members"; masses are measured into "portions"; activities and processes have "features"; areas can be divided into "places" and so forth. There are at least 40 such part terms, narrower in scope than "part" but with a fairly wide range of application. There is also a much larger number of highly specialized terms, for example, "shard," "tithe," "zone." etc. *Roget's Thesaurus* (1962) lists approximately 400 synonyms for "part."

Specialized part terms can sometimes be used to distinguish among meronymic relations, as in,

(13a) Simpson is a *member* of the Philosophy Department.
(13b) The carburetor is a *component* of the engine.

Bizarre relationships are suggested by

*(13a) Simpson is a *portion* of the Philosophy Department.
*(13b) The carburetor is a *member* of the engine.

It is possible that specialized part terms correspond to and label distinct meronymic relations. We have suggested, for example, that "component" names the relation between integral objects and their parts. In another paper (Chaffin, Herrmann, & Winston, 1987), we report on an empirical study designed to test this hypothesis by asking subjects to sort meronymic relations and to select part terms which can be used to express them. For the present, however, we emphasize the point that "part," is the most general of all part terms, and is vague in the same way that many other general terms are vague, for example, "game," "container," or "red." (Anderson & Ortony, 1975; Cruse, 1986, p. 81).

Finally, it must be noted that much confusion arises because the same sentence can be regarded in several different ways. For instance, the sentence, "The Capitol is part of Washington." might mean that the Capitol

building is a place within the area of Washington D.C.; or "Washington" might denote a complex artifact one of whose components is the Capitol; or Washington might be seen as a collection of buildings one of which is the Capitol; or the same sentence might be interpreted as elliptical for, "Part of going to Washington is seeing the Capitol," in which case it expresses the feature-activity relation. Particular instances of relations are often ambiguous (Chaffin & Herrmann, 1984).

5. THE TRANSITIVITY PROBLEM

We will now discuss how this taxonomic scheme can explain cases of apparent intransitivity of meronymy that have been difficult to account for in previous analyses.

The transitivity of the class inclusion relation enables it to support valid syllogistic inferences, such as,

(14a) Hamburg is a city.
(14b) Cities are human settlements.
(14c) Hamburg is a human settlement.

Meronymic relations appear to be transitive such that, if A is part of B, and B is part of C, then it follows that A is part of C, as in,

(15a) The carburetor is part of the engine.
(15b) The engine is part of the car.
(15c) The carburetor is part of the car.

However, a number of authors (Cruse, 1979, 1986, pp. 165-168; Lyons, 1977, pp. 311-317; Miller & Johnson-Laird, 1976, p. 240) have noted that inferences of this kind, or what we will call "merological syllogisms," do not always appear to be valid, and several explanations for the apparent failures of transitivity have been advanced.

In (16) the term "part" is used throughout in the component-object sense:

(16a) Simpson's finger is part of Simpson's hand.
(16b) Simpson's hand is part of Simpson's body.
(16c) Simpson's finger is part of Simpson's body.

However, when different types of meronymic relations are combined in the same argument, as in (17), the "part of" relation is not transitive and the inference is not valid.

(17a) Simpson's arm is part of Simpson.
(17b) Simpson is part of the Philosophy Department.
*(17c) Simpson's arm is part of the Philosophy Department.

The falsehood of (17c) is due to an equivocation on "part of" between (17a) and (17b). "Part of" in (17a) is understood as a component-object relation and in (17b) as a member-collection relation. The failure of transitivity in (17) is due to the mixing of these two types of meronymy, so that the conclusion (17c) is false (as well as strange), since Simpson's arm is neither a component nor a member of the Philosophy Department.

We can see more clearly how this sort of equivocation works by substituting a specialized part term in the above frames to make it clear which meronymic relation is expressed in each premise,

(17a') Simpson's arm is a component of Simpson's body.
(17b') Simpson is a member of the Philosophy Department.
*(17c') Simpson's arm is a component/member of the Philosophy Department.

Thus, it seems, that when we inadvertently equivocate between the component-object and the member-collection senses we get invalidity, as well as strangeness (*cf.* Cruse, 1979, p. 30).

We might then suppose that equivocation produces strangeness and invalidity in all cases. But consider,

(18a) The head is part of the statue.
(18b) The statue is part of the Etruscan collection.
?(18c) The head is part of the Etruscan collection.[5]

(18) would seem to be parallel to (17), yet there is nothing strange nor obviously false with the conclusion expressed in (18c). Since "part of" in (18a) is component-object, while in (18b) it is member-collection, our analysis would appear to predict that (18c) should be invalid and sound strange—but it does not seem to.

The solution to this problem lies in the vagueness of the term "part." The reason (18c) is acceptable is that it is possible to regard the head of a statue as "part," (in the member-collection sense), of a museum's collection whether or not it is attached to a torso. (18) thus differs from (17) in that the heads of statues, in this context, can accept a sense of "part" (the member-collection sense) which arms of living persons cannot. By itself, (18c) sounds perfectly acceptable, while (17c) sounds strange at best.

But, does (18) also contain a valid inference? The answer we give is "no." While it may in fact be true that the head of the statue might be regarded as a member of the collection in its own right, it does not follow logically from these premises that it is. If we interpret (18c) as expressing the member-collection relation, then we must also assume that the head is separated from the statue, and hence individuated as a separate item in the collection. Since

[5] We are indebted to an anonymous reviewer for this example.

this assumption is not warranted by any information supplied by the premises, the conclusion expressed by (18c) on this interpretation does not follow. Alternatively, we may interpret (18c) in the component-integral object sense by appealing to a metaphorical use of the term "component" in which the head is understood as the centerpiece or prominent example of a collection which has been organized around it. Again, this assumption is not warranted by the premises and the conclusion does not follow.

Failures of transitivity based on equivocation among the senses of "part" also occur in other cases. Consider, for example, the following failure of transitivity:

(19a) The refrigerator is part of the kitchen.
(19b) The kitchen is part of the house.
?(19c) The refrigerator is part of the house.

The apparent falsehood of (19c) suggests that two different meronymic relations are involved, a component-object relation in (19a) and a place-area relation in (19b). While refrigerators are often functional parts or components of kitchens, a kitchen is merely a place within a house, not a component of the house. While the vagueness of "part" allows most people to say (19b), the failure of transitivity to (19c) reveals the confusion of the component-object sense of "part" with the place-area sense.

Two other possible causes of intransitivity are discussed by Cruse (1979, 1986, pp. 165–168) for cases like (19). Cruse uses the "has" frame to construct merological syllogisms such as,

(20a) The door has a handle.
(20b) The house has a door.
*(20c) The house has a handle.

Cruse provides two different explanations for this example. First, he points out, the "handle" in (20a) does not move the house (but only the door) and so the house is outside the "functional domain" of the handle. He suggests that the failure of transitivity in this case is due to incorrectly extending the functional domain of handle to house. However, a car is similarly outside of the functional domain of a Venturi valve, yet a valid argument similar to (20) can be constructed using the terms "Venturi valve," "carburetor," and "car."

Second, Cruse observes that the relation in (20b) might be viewed as attachment rather than part-whole. While the part-whole relation is transitive, the attachment relation is not. The inference to (20c) could thus be invalid because the relation expressed in (20b) is viewed as attachment, not meronymy. This seems to be correct. If we interpret (20) using the component-object sense of "part" throughout, then the inference is perfectly acceptable. The component interpretation of (20a) is strengthened by the use of "door handle" in place of "door":

(20a') The (door) handle is part of the door.
(20b') The door is part of the house.
(20c') The (door) handle is part of the house.

The door handle is clearly not attached directly to the house, but rather to the door, which is why, as Cruse notes, the syllogism seems to be valid when we say that the house has a door handle instead of just a handle. This account is consistent with our explanation of intransitivity as due to the combination of different relations in the same syllogism. Our analysis further suggests that we can choose to focus on attachment in understanding (20a), that is, "The handle is attached to the door," or on meronymy, that is, "The handle is a part of the door." In the latter case, the syllogism is valid.

But then, what are we to say about,

(21a) Fingers are part of the hand.
(21b) The hand is part of the arm.
(21c) Fingers are part of the arm.

which, on one interpretation, as Cruse notes, suggests some sort of deformity. The oddness of (21) arises if we think of "part of" as expressing attachment rather than merological inclusion. Fingers are merologically included in arms (normal ones anyway), though they are not directly attached to arms. In this case, as in (20), failures of transitivity are explained by our confusing the meronymic inclusion relation with the attachment relation.

So long as we are careful to keep to a single sense of "part" in examples like these it seems that the part-whole relation is always transitive. However, when we inadvertently mix different meronymic relations problems with transitivity arise. If this hypothesis is correct, we should be able to find cases of the failure of transitivity for each pair of meronymic relationships. We have already demonstrated the failure of transitivity for several pairs. Examples for all 15 possible combinations of the six types of meronymic relations are presented in Appendix 1.

6. TRANSITIVITY AMONG INCLUSION RELATIONS

The account we have given of the transitivity of meronymy predicts that failures of transitivity arise when different types of meronymy are combined in standard form syllogisms. What happens, though, when meronymic relations are combined with other inclusion relations? Are the resulting arguments always, sometimes, or never valid?

We distinguished merological inclusion from class inclusion, and spatial inclusion. Consider first what happens when we combine meronymy and class inclusion in the premises, as in,

(22a) Wings are parts of birds. MER

(22b)	Birds are creatures.	CL
(22c)	Wings are parts of creatures.	MER

This seems perfectly valid, while the same syllogism with the alternate conclusion,

*(22d)	Wings are creatures.	CL

is clearly invalid. Note that when this syllogism is in standard form, the meronymic relation which is expressed in the valid conclusion (22c) comes from the major premise.

A similar pattern is found when we combine meronymic premises with spatial inclusion, as in,

(23a)	The wheel is part of the bike.	MER (C-IO)
(23b)	The bike is in the garage.	SP
(23c)	The wheel is in the garage.	SP
*(23d)	The wheel is part of the garage.	MER

But here, although only one conclusion is valid, this time the relation expressed in the valid conclusion, spatial inclusion, comes from the minor premise.

When we mix class inclusion with spatial inclusion we get,

(24a)	Socrates is in Athens.	SP
(24b)	Athens is a city.	CL
(24c)	Socrates is in a city.	SP
*(24d)	Socrates is a city.	CL

Here again, the valid conclusion expresses spatial inclusion which was found in the major premise. The same pattern is found when we mix class inclusion with other types of meronymic relations, e.g., stuff relations,

(25a)	Pies are a kind of dessert.	CL
(25b)	Desserts are partly sugar.	MER (S-O)
(25c)	Pies are partly sugar.	MER (S-O)
*(25d)	Pies are a kind of sugar	CL

Here the valid conclusion expresses meronymy, but unlike (24) the premise expressing this relation is the minor premise.

These results suggest that a hierarchical ordering exists among these types of inclusion relationship, such that mixed inclusion relation syllogisms are valid if and only if the conclusion expresses the lowest relation appearing in the premises, where the ordering of relations is:

CLASS INCLUSION > MEROLOGICAL INCLUSION > SPATIAL INCLUSION

The hypothesis that inclusion relations are hierarchically ordered in this way appears to account well for the data. We must now attempt to explain why the transitivity of inclusion relationships follows this pattern.

7. RELATION ELEMENT THEORY

We have described four phenomena that require explanation. First, there are several types of meronymy. Second, there are several nonmeronymic relations that are similar to meronymy in different ways. Third, the term "part of" is a general expression that can be used in place of a large number of more specific part terms. Fourth, there is a complex but regular pattern to the transitivity of inclusion relations. We will outline a theory of semantic relations that provides a general framework for explaining these observations.

A framework for our analysis of meronymy is provided by relation element theory which accounts for the character and behavior of semantic relations in terms of more primitive relational elements (Chaffin & Herrmann, 1987, pp. 221-245; Herrmann & Chaffin, 1986). According to this theory a semantic relation (R) between two concepts (x and y) is a complex structure composed of one or more primitive dyadic relation elements (Ea...En) that are supported by the meaning of the two concepts.

xRy → (Ea...En)

Relations may share one or more elements. The greater the proportion of elements two relations have in common, the more similar they are. Thus xRy is more similar to iRj than to mRn:

xRy → (E1, E2, E3)
iRj → (E1, E2, E4)
mRn → (E1, E4, E5)

Relation elements may be hierarchically organized so that the presence of one *dependent* element (E2) can only occur when another *independent* element is present.

xRy → (E1(E2))

7.1 Diversity

What are the elements of meronymic relations? We cannot provide a complete answer to this question, but we can suggest some parts of it. Central to meronymy is a *connection* between a whole and its parts. The nature of this connection varies with the type of meronymy. The variation is captured by the three elements that were used in Table 1 to summarize the differences between the types of meronymy. The connection of part to whole differs depending on whether the part is *functional, homeomerous,* and *separable.* Variation in these elements is responsible for many of the differences among the types of meronymy that we have surveyed. Connection is thus an independent element common to most meronymic relations and the elements of

functionality, homeomerity, and separability are dependent on it. We can express this for the integral object-component relation (e.g., *handle-cup*) as,

xRy → (Connection, (Functional, Nonhomeomerous, Separable).

7.2 Similarity

Three elements are sufficient to distinguish the types of meronymy that we have described, but these relations undoubtedly have other elements. Other elements are needed to account for the similarity of meronymy to some nonmeronymic relations. For example, some types of meronymy have the element of *possession,* as expressed by "belongs to" in sentence frames like, "The A belongs to the B", for example, *wheel-car.* Other types of meronymy do not involve possession, for example, *spelling-writing.* Meronyms that do have this element are similar in this respect to the nonmeronymic relation of ownership, for example, *millionaire-money,* which involves the same element.

All similarity judgments require that the two things compared be decomposed into aspects or elements in which they are the same and aspects in which they differ (Tversky, 1977). This is expressed in the aphorism, "You can't compare apples and oranges." This is true if apples and oranges are considered as unanalysable wholes. But when the wholes are decomposed into aspects in which they are the same (shape, size, nutritional value), and different, (texture, taste, color), the comparison is easily made. In the same way, the perception of similarity between semantic relation requires that the relations be decomposed into elements.

Similarity between relations is readily recognized by people untutored in linguistic theory. Chaffin and Herrmann (1984) presented undergraduate students with word pairs exemplifying 31 different semantic relations, including five types of meronymy, in a sorting task. Subjects were asked to sort the word pairs into groups, putting similar relations into the same group and different relations into different groups. A hierarchical clustering analysis of the data yielded a taxonomy of relations that corresponded fairly well to taxonomies based on linguistic analysis. The similarities between relations represented in the taxonomy were accounted for by relation elements for the 31 relations derived from the linguistic literature (Chaffin & Herrmann, 1987; Stasio, Herrmann, & Chaffin, 1984). In another paper we will report the results of a similar sorting study of meronymic relations (Chaffin et al., 1987).

The readiness with which the similarity of relations is evaluated suggests that decomposition into elements is normally involved when semantic relations are recognized, and is not something that requires a deliberate effort or prolonged reflection. This is indicated by the effect of relation similarity on the latency of semantic decisions. In semantic decision tasks subjects are

presented with pairs of words and asked to decide whether each pair is an example of a particular target relationship, e.g., class inclusion, meronymy, or antonymy. The speed of these decisions is affected by the similarity of the relation of the stimulus pair to the target relation that subjects are asked to identify (Chaffin & Hermann, in press; Herrmann & Chaffin, 1986; Herrmann, Chaffin, Daniel, & Wool, 1986; Hermann, Chaffin, Conti, Peters, & Robbins, 1979). People evaluate the similarity of relations even when they are not explicitly asked to do so and when they are under time pressure to make rapid judgments.

7.3 Vagueness

The term "part of" is a superordinate term for a large class of more specific meronymic relations many of which have names in English, for example, "component," "portion." The concept *part* behaves like other natural categories, for example, *games* (Wittgenstein, 1968), *cups* (Labov, 1972) and *color* (Carroll, 1985). We can draw four parallels between the concept of a *part* and other concepts. First, instances of the concept are united by a family resemblance (Rosch, 1975) which we have characterized by the elements *inclusion* and *connection*. Second, the boundaries of the concept are fuzzy and shade into other classes at the edges; for example, *"exhibit-display"* can be regarded as a case of meronymy, class inclusion, synonymity or as a coordinate relation. Third, the large number of specialized terms for types of meronymy in English (e.g., "component," "portion") suggests that "part of" may be the "basic level" of description for this type of relation (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). Fourth, the term "part" is vague, and is instantiated by its context, as are other general terms (Anderson & Ortony, 1975).

7.4 Transitivity

We made three observations about the transitivity of meronym relations which must be explained. First, meronymy is transitive when the same kind of meronymic relation occurs in both premises of a syllogism. Second, apparent failures of transitivity occur when different types of meronymy occur in the two premises of a syllogism. Third, different types of inclusion relation are transitive, but only if the conclusion contains the relation which is lower in the hierarchy of inclusion relations.

Before we can account for these three phenomena it will be necessary to describe the hierarchy of inclusion relations in terms of relation elements. Briefly, spatial inclusion is the simplest of the three inclusion relations with the single element of *inclusion*. Meronymy adds to this a second element, *connection*. Class inclusion is the most complex, adding a third element, *similarity*. Simple inclusion is a topological relation in which one thing surrounds another, but the two things are otherwise separate, for example, *West Berlin-East Germany*. This relation may be modified by the dependent

elements *space* or *time*. Meronymy involves the element of simple inclusion and, in addition, the independent element of *connection*. *Connection* may be modified by dependent elements specifying the type of connection. The type of meronymy is determined by these dependent elements.

Class inclusion has the elements of *inclusion* and *connection,* but in place of the requirements for a specific type of connection it has another independent element of *similarity,* for example, the requirement that each member be similar to other prototypical members (Herrmann et al., 1986; Rosch, 1975). The type of similarity may be modified by dependent elements that determine the type of class inclusion relation (Wierzbicka, 1984).

With this account of the hierarchy of inclusion relations we are in a position to explain the transitivity phenomena we have observed. The three transitivity phenomena are explained by a single principle.

The principle of element matching: A syllogism is valid if and only if the conclusion contains only those relation elements common to both premises.

Three corollaries of this principle correspond to the three observations.

1. A syllogism is valid if the same kind of meronymy occurs in both premises and conclusion. This is because identical relation elements occur in both premises and in the conclusion.
2. A syllogism is invalid if different meronymic relations occur in the two premises. This is because, whichever relation appears in the conclusion, it will have at least one element that does not appear in one of the premises.
3. A syllogism containing different kinds of inclusion relations is valid if the conclusion contains the relation lower in the hierarchy, but is invalid if the conclusion contains the relation higher in the hierarchy. This is because the elements of relations lower in the hierarchy are common to relations higher in the hierarchy. If the conclusion contains the relation lower in the hierarcchy then it will contain only elements common to both premises.

8. CONCLUSION

Our interest in distinguishing between different types of relations runs counter to a long tradition in logic in which it has been found productive to ignore differences among semantic relations and to focus on logical form alone. Traditional accounts of syllogistic reasoning, for instance, found it convenient to assimilate all forms of predication to class membership. For example, "G is regretful" was treated as "G is a member of the class of regretful people." This tradition is partly responsible for the paradox that has arisen over the transitivity of the part-whole relation. The solution to

this paradox is to distinguish different types of meronymic relations and to distinguish meronymy from class and spatial inclusion.

The suggestion that semantic relations can be decomposed into more basic elements also runs counter to a corresponding tradition in psychology in which relations between ideas are treated as unitary entities that function as the primitives of psychological explanations. For example, network theories of semantic memory (Anderson, 1976; Shank & Abelson, 1977; Norman, Rumelhart, & the LNR Group, 1975; see reviews by Chang, 1986; Johnson-Laird, Herrmann, & Chaffin, 1984) represent relations as labelled links between nodes that represent concepts. The links account for other phenomena but are not themselves further explained. The labelled links representing semantic relations thus function as theoretical primitives in these models.

The approach we have taken here has been to view the semantic relations found in network and frame theories as analysable into more primitive elements. Applying this approach to the analysis of meronymy has enabled us to distinguish several different types of meronymic relations, to distinguish meronymy from other semantic relations, to account for apparent failures of transitivity in merological syllogisms, and to explain the curious patterns of transitivity among inclusion relations.

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APPENDIX 1

Pairwise Combination of Sentences Expressing Six Types of Meronymic Relations. In each case the conclusion is invalid, and in many cases odd (indicated by * or ?).

IA. Component-Integral Object: Member-Collection

Simpson's finger is part of Simpson.
Simpson is part of the Philosophy Department.
*Simpson's finger is part of the Philosophy Department.

IB. Component-Integral Object: Portion-Mass/Object

A windshield is a part of a car.
This shard was a part of a windshield.
*This shard was a part of a car.

IC. Component-Integral Object: Stuff-Object

Water is part of the cooling system.
Water is partly hydrogen.
*Hydrogen is part of the cooling system.
?The cooling system is partly hydrogen.

ID. Component-Integral Object: Feature-Activity

A handle is part of a spoon.
A spoon is part of eating soup.
*A handle is part of eating soup.

IE. Component-Integral Object: Place-Area
A refrigerator is part of a kitchen.
A kitchen is part of a house.
*A refrigerator is part of a house.

IIB. Member-Collection: Portion-Mass/Object
The plate is part of the dinner service.
This shard was part of the plate.
*This shard was part of the dinner service.

IIC. Member-Collection: Stuff-Object
Trees are parts of forests.
Trees are partly cellulose.
*Cellulose is part of forests.
?Forests are partly cellulose.

IID. Member-Collection: Feature-Activity
The joker is part of a deck.
A deck is part of playing bridge.
*The joker is part of playing bridge.

IIE. Member-Collection: Place-Area
This tree is part of the Black Forest.
The Black Forest is part of Germany.
*This tree is part of Germany.

IIIC. Portion-Mass/Object: Stuff-Object
This square is part of my candy bar.
My candy bar is partly almonds.
*This square is partly almonds.
?Almonds are part of this square.

IIID. Portion-Mass/Object: Feature-Activity
This slice is part of the wedding cake.
The wedding cake is part of getting married.
*This slice is part of getting married.

IIIE. Portion-Mass/Object: Place-Area
These grains of sand are part of the beach.
The beach is part of the island.
?These grains of sand are part of the island.

IVD. Stuff-Object: Feature-Activity/Event

The boat is partly fiberglass.
The boat is part of the race.
*Fiberglass is part of the race.
*The race is partly fiberglass.

IVE. Stuff-Object: Place-Area

The Capitol building is partly marble.
The Capitol building is part of Washington.
?Washington is partly marble.
*Marble is part of Washington.

VE. Place-Area: Feature-Activity/Event

The Grand Canyon is part of the United States.
The United States was part of World War II.
*The Grand Canyon was part of World War II.