Similarity and Categorization : Taxonomic and Meronomic parts of Similes

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Summary. A category is a three terms "concept": the category itself denoting a group of objects and a group of shared properties, its extension (the objects it groups) and its intension (the shared properties). Of what is a category made of? What are the parts of a category? We advance that parts of a category are the properties of this category, which is to say that parts of the definition of a category are the properties listed to describe this category. The color "grey", which is not a physical part of a mouse, is a part of the description of the "mouse category", as well as "moustache" which can be a physical part of a given mouse and a part of the description of the "mouse category". This is to say that a clear distinction should be made between physical objects and cognitive categories. We shall name *partonomy* the decomposition of an object into its physical parts and *meronomy* the decomposition of a category description into its cognitive parts and show how this approach helps solving some of the similarity problems.

1 How much similar is a mouse with an elephant?

How much similar is a mouse with an elephant? Measuring similarity is a key problem in A.I. and in Cognitive science and a solution that would help to find out how much something (an object, an image, an idea, a text, a situation, a discovery) is similar to something else would be helpful for detection, identification, analogy, thinking, and problem solving (Tijus, 2001, Goldstone & Son, 2005). The usual problem is a basic decision making based on signal detection that can be expressed as follows: given some knowledge about x, to measure how much y is similar to x and to accept or reject y as being of the same kind than x. Object x can be some individuals and y another individual, x a single recorded signature and y any signature, x a definition and y an instance. Signal detection theory is useful for evaluation how good a detection system is, if it is possible to define *what x is* and *what x is not*. Contrary to the ideal receiver theory, we usually do not know what x is, and what x is not. Thus a first problem, - the definition problem-, is to find the right dimensions from which x and y can be compared, which means having a right description of x.

Let's suppose the definition problem being solved. The signal detection decision making problem is, having some similarity values as input, to provide as output some categorization decision about y: at least y "*as being of the same kind than x*", or "*not being of the same kind than x*". Surprisingly, studies in cognitive psychology show that similarity does not match categorization (see Goldstone, 1994; Medin, 1989 for a review).

Much more: first, similarity is not transitive: For instance, having similarity (Russia, Cuba) = 7 and similarity (Cuba, Jamaica) = 8, then, one should expect similarity (Russia, Jamaica) being around 7, but the similarity score is quoted =1! A problem that is taken into account by Nonmetric multidimensional scaling (MDS) models, from Richardson's (1938) ideas, that consider that dimensions for comparison differ in the Russia-Cuba case and in the Cuba-Jamaïca case. Second, similarity is asymmetric (Tversky, 1977): x can be quoted more similar to y, than y to x. The letter « F » is more similar to « E », than « E » to « F ». Third, people put in different categories things that they evaluated to be very similar (Rips & Collins, 1993). Let's take the signature problem. It could be that if you ask someone how much signature x is similar to signature y of someone, you may have a different score than if you ask how much similar is y to x. You can find the case in which signature z was found very similar to y, and y very similar to x, but z dissimilar with x. And finally, you will have the case in which signature y is judged very similar to signature x of person P, but being evaluated as not being signature of person P. The signature example sounds plausible, although with no rational at all.

As a solution, it could be that natural categorization is guided by similarity, but that people do optimize categorization performance paying attention to some core properties that have less weight in similarity than in categorization (Nosofsky, 1986). Another solution is that categorization is not being guided by similarity, but similarity being guided by categorization. We argue that similarity is the output of categorization and not the reverse. Thus the problem at hand is how are built categories and how similar objects can belong to different categories and how dissimilar objects can belong to a same category.

We present the contextual reciprocal effect theory of categorization (Poitrenaud, Richard & Tijus, 2005; Tijus, 2001) and how it may help solving some of the similarity-categorization problems.

2 /Mammal/ is part of both /Elephant/ and /mouse/

The physical and ecological world is composed of objects. Any object has a number of parts and an arrangement of these parts that defines its structure. Any object has also features along physical dimensions (what is made of, shape, color, brightness,..) and cognitive (non-physical) dimensions (functionality and usability). Verbal descriptors of one object can comprehend words that designate parts, the way parts are arranged, as well as physical and cognitive features. Contrary to physical objects, categories are mental or cognitive entities. They are representation of groups of objects for cognitive purpose: identification (this is a cat), inference making (should like having milk), and so on. Thus, a category is a three terms "concept": the category itself as a group of objects and a group of shared properties, its extension (the objects its groups: games) and its intension (the criteria for grouping : to play with).

Also for cognitive purpose, categories entail categories (cats are animals, objects saved from the fire are objects of the burning house, material games are objects). As entailment of categories forms hierarchy of categories, we shall use the term *taxonomy* with a *"is a kind of"* link between categories (a cat *is a kind of* animal, an animal *is a kind of* living thing).

Our approach focuses on what is a category made of ? What are the parts of a category? We advocate that parts of a category are the criteria for grouping and differentiating: the properties of this category, which is to say that parts of definition of a category are the properties listed to describe this category. The color "grey", which is not a physical part of a mouse, is a part of the description of the "mouse category", as well as "moustache" which is a physical part, as well as a part of the description of the "mouse category". This is to say that a clear distinction should be made between physical objects and cognitive categories. We shall name *partonomy* the decomposition of an object into its physical parts and *meronomy* the decomposition of a category description into its cognitive[1] parts.

This is the theoretical ground on which, we advocate first, that taxonomy and meronymy are two sides of a same coin, "X *is a kind of* Y and Y *a part of* X", - what Rips & Conrad (Rips & Conrad, 1989; Fellbaum & Miller, 1989) named *the reciprocal effect* -, and second, that this approach helps solving the similarity-categorization problem.

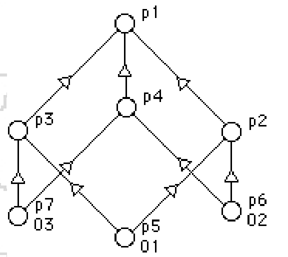
[1] The distinction between "physical "and "cognitive" is to distinguish between physical properties, which are properties of a present object and that can be captured by physical instruments (color, weight, shape, parts, and so on) and properties that are listed in the absence of the object (Lakoff, 1986).

3 The reciprocal effect of categorization

Categorization is the ability to group objects in hierarchy of categories. We focus on categorization instead of category because the cognitive need of a category is not mainly *to group*, but *to differentiate between objects*. For instance, since someone in a zoo starts saying "*lions*...", she is starting talking about "*lions*" among “*other things*” and differentiating almost between three sets: "*things*", "*lions*" and "*no-lions among things*". If she follows talking about "*lions and tigers*", she is defining five sets, "*things*", "*lions*", "*tigers*", "*lions and tigers*" and "*no-lions-or-tigers among things*". The category "*lions and tigers*" might be cognitively described as "*human killer animal, big cats, and so on*", whatever supposition about the reason that justifies the grouping of lions and tigers and can be summarized as "*you are talking of human killer animal?*." “*No, I want to say that lions and tigers are nice big cats!*.”

To differentiate between objects is made by building subcategories and, doing so, hierarchies of categories. Hierarchies of categories have a mathematical formalism labeled Galois Lattices (Barbut & Monjardet, 1970; Poitrenaud, 1995) that permits to create the one hierarchy of categories with transitivity, asymmetry and reflexivity, when given the $O_n \ X \ P_m$ boolean matrix which indicates for each of the *n* objects, if it has, or if it has not, each of the *m* properties. The maximum number of categories is either 2^{n-1}, or m if m < 2^{n-1}, in a lattice whose complexity depends on the way properties are distributed over objects (figure 1).

	p1	p2	p3	p4	p5	p6	p7
01	1	1	1		1		
02	1	1		1		1	
03	1		1	1			1



	p1	p2	p3	p4	p5	p6	p7
01	1	1	1		1		
02	1	1		1		1	
03	1	1		1			1

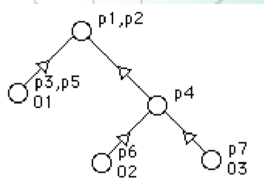


Figure 1. Binary descriptions and corresponding Galois Lattices

Hierarchies of Categories, as in figure 1, have the inheritance principle of taxonomies (*if birds are animals, birds have in addition of their own properties, properties of animals*). For instance in figure 1b, object O1 is an instance of category P3,P5 which has category P1,P2 as superordinate. If P1 is "on the table", P2 "red", P3 "large" and P4 "square", O1 would be here a kind of "large square" that is a kind of "red thing on the table"; O2 and O3 being for instance small (P4) triangle (P6) and rectangle (03).

Let us label X the category made of P1,P2 and Y the category made of P3,P5. Y is a kind of X. Due to the inheritance principle, category Y includes P1,P2 the properties of category X. This can be seen in the boolean table of figure 1b. As Rips & Conrad (1990, footnote 3) reported as being the property hypothesis of the reciprocal effect: "*If Y is a kind of Y, then Y must have all the X's defining properties*" (as in traditional property models of classification- see Smith & Medin, 1981). As a consequence, the Galois lattice formalism, as well as the property hypothesis, advocate that "*mammals are part of elephants, tools are parts of hammers*" in the sense that "*all the description of mammals are part of the description of elephant and that all the description of tools are part of the description of hammers*". Contrary to Rips & Conrad (1989, p. 201) who wrote "*More general classes of objects don't seem to be parts of more specific ones -mammals are not parts of elephants, tools are not parts of hammers, and so on-*".

The fact that the sentence "*mammals are part of elephants*" seems false, or at least counterintuitive, comes from the confusion between intension and extension. The meaning of the sentence "*mammals are part of elephants*" seems to be that all the objects that are mammals are part of all the objects that are elephant. What is truly false. But not the sentence "*what one can say of mammal is a part of what one can say of elephant*" that sounds differently and could be experimentally verified with participants, even if it is an implicit knowledge.

Contrary to objects that have a physical counterpart, categories are cognitive. We advance that all the psychological facts that are related to categories must be studied as thinking and require, as such, verbal thinking judgment responses from participants. "*Are elephants mammals?*" is a question based on a cultural setting and should be reformulated as such. "*Are elephants said to be mammals?*" is a better proposal. It is the way to distinguish between what the object "*elephant*" is (*e.g., having mammals*) from what the category "MAMMALS" is, since there is nothing in the world that would have only the properties of MAMMALS. The abstraction of properties from objects in order to form categories is a cognitive fact and has to be dealt as such.

What means /ANIMAL/ *is part of* /MAMMAL/. The cognitive parts we talk about could match the physical parts of physical objects. Facing a real car: "*This is a car* (whole)" entails the sentence *"This has an engine* (part)" and "*this car is a kind of thing with engine* (taxonomy)". If it is the case that *"A leaf is a part of tree," then it is the case that "a tree is a kind of things with leaves.*"

However, we are partisan of a clear distinction between objects of the physical world and categories used to represent them, to think, talk and communicate about them, for the followings. First, a category, which is cognitive, cannot be something in the physical object ("to draw a mutton" does not tell you "what real mutton you should draw"). In opposite, properties in categories can be properties in other categories. Second, in some cases properties might correspond to descriptions of physical parts of objects. Thus, as properties of superordinate categories are properties of their subordinates, taxonomies built only with description of physical parts follow the rule that "*part properties of categories are part properties of their subordinate*". For instance, "*squares are rectangles*" entails that "*parts of rectangles (four sides, opposite parallel sides of same length, four right angles) are parts of squares*". This taxonomic relation appears to be converse to the whole-part relation: "*rectangles are made of parallel sides*", "*rectangles are kind of parallel sides figures (parallelograms).*" Its follow that the whole-to-part Galois lattice is just the reverse of the taxonomic Galois lattice. The corresponding *part-of* graph of the *kind-of* graph of figure 1-bottom is just the reverse, top-down, graph. So, Figure 1-bottom can also be read as a *part-of* graph. Suppose that 01 is ELEPHANT having nail (p3), defense (p5), but also having mammals (p1) and four legs (p2) as other ANIMALS who have fur (p4) such as 02-MONKEY with long tail (p6) and O3-CAT with moustache (p7). In figure 1-bottom, mammals (p1) and four legs (p2) are common parts of ELEPHANT (O1), MONKEY (O2) and CAT (O3), while fur (p4) is part of MONKEY (O2) and CAT (O3).

However, parts properties are description of physical parts, not the physical parts *per se* and properties are of many kinds. All the properties of any kind of a category are a subset of all the properties of a subordinate category: all the part of the description of MAMMALS (such as to have a head, a body, mammals, and so on, but also to breathe, to nurse, which are not part properties) are parts of the description of ELEPHANT, the reverse not being true (horn). The meronomic relation is the *part of* relation between description, including description of physical parts. The meronomic "part of" relation appears to be converse of the kind of taxonomic relation:

4 Testing the reciprocal effect of categorization

For two categories X (e.g. elephant) and Y (e.g. Animal) testing a X-to-Y reciprocal effect is a three terms question: 1. Does *X kind-of Y* imply *Y part-of X* ?; 2. Does *Y part-of X* imply *X kind-of Y* ?; 3. Does *X kind-of Y* imply *Y part-of X* and *Y part-of X* imply *X kind-of Y*?. Terms 1 and 2 are oriented reciprocal effect, while term 3 is the plain reciprocal effect. A *kind-of*-to-*part-of* oriented reciprocal effect can be observed when *kind-of* implies *part-of,* but not the reverse (Figure 2).

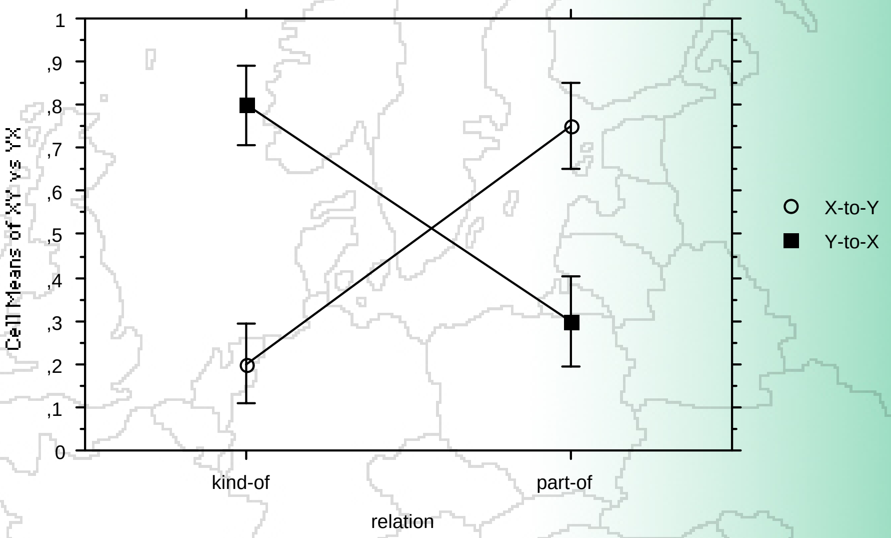


Figure 2. Expected data from the reciprocal effect of catégorization hypothesis : if Y is king of X (high YES score), then X is not Kind of Y (low YES score), X is part of Y (high YES score) and Y is not part of X (low YES score).

Running four experiments, forty participants for each experiment, we tested the reciprocal effect of categorization using animals and plants (experiment 1), parts of animals and parts of plants (experiment 2), verbs of displacements (experiment 3), and the set of verbs of mental activities used by Rips & Conrad, and verbs provided by Fellbaum & Miller (experiment 4).

There was no significant difference either between taxonomy and meronomy or between the two orders of presentation (X-to-Y vs Y-to-X). In opposite, the predicted interaction, (taxonomy vs. meronomy) x (X-to-Y vs. Y-to-X), was always found (Table 1).

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Table 1. Either for categories (left table) or for parts (right table), the reciprocal effect was found in the whole sets of experiments: no X-to-Y effect, no difference between kind-of and part-of, but a strong order-relation interaction effect.

"*Why aren't mammals part of elephants?*" ... *"Although elephants are kinds of mammals and knees (for example) are parts of elephants, knees are not kinds of mammals."* (Rips & Conrad, 1989, p. 202).

Contrary to Rips and Conrad, we argue that "MAMMAL is part of ELEPHANT" and that, given that knees are parts of elephants, ELEPHANT is a kind of KNEES's OBJECT, a reciprocal effect that we found with people. Our point of view is that Rips & Conrad, as well as Fellbaum & Miller didn't distinguish between words and the categories denoted by words, and between category extension and intension. For instance, Fellbaum & Miller (1989) write "The entailment relation between nouns must be strictly distinguished from the meronymic relation, which is always independent of, and never included in, the hyponymic relation "*a leaf is a part of tree*" but it is not the case that "*a leaf is a kind of tree.*" (p.569). First, a "*noun*" entails nothing per se, but what it refers to, may entail something. The noun *"leaf"* doesn't entail *per se* "*is a part of tree*". It is a for a certain person, in a certain context that the noun "*leaf*" will evoke something that is a part of a tree (for instance, in a sentence like "*the wind blows the leaves*") or will not evoke something that is a part of a tree ("*the wind blows the dead leaves*"). Second, the "s*omething*" which is designed par the word "*leaf"* maybe not an object, but a category: that "*leaf"* as "*any oak leaf"* ("*that leaf... is missing in my leaves collection*"). Such as Lakoff (1986), Tijus & Moulin (1997), and others, we think that nouns designate categories of objects in which real objects can be instantiated in the context of a situation ("*look that leaf*"), or of a representation ("*the autumn dead leaves*..", A. Rimbaud), which means that categories are built up on line, as contextual categories.

5 The reciprocal effect of categorization: a key for similarity

Categories are very sensitive to context (Tijus, 2001), in a sense that properties of the category will be depend on the context: in "*to move the pieces of furniture*", or in "*to polish furniture*", that are two understandable sentences, furniture does not have the same set of properties, neither the same extension: in wood would be included in the furniture to polish. Properties are themselves abstraction.

The cognitive reciprocal effect is that people can build up categories from part of the description of the object at hand. Suppose that "*Peter has just bought a car*", the contextual reciprocal effect theory argue one does create the category of "*things Peter has bought*", in which "*the new car*" is instanced. The old car that was given to Peter by his mother would be less similar than the new house Peter already just bought. To put in the same category both the car (expensive) and the house (expensive) makes infer that Peter is rich. Thus the contextual reciprocal effect theory is mainly a theory about understanding, thinking and reasoning.

How can be things in a same category being dissimilar? Dissimilarity judgment is furnished by the hierarchical structure of categories entailment. The ultimate case of a same person (thus in one category: *the individual*) can be represented in two subcategories (*the individual a long time ago*, *the individual now*) when one sees a friend after a long times: "*have you seen how much peter has changed: I did not even recognize him*." This allows also understanding what "*same*" means in sentences such as "*Peter and Paul have the same Pant*" (two pants of the same kind) vs. "*Peter and Paul have the same girlfriend*" (an unique person).

Return to the signature example. How to evaluate if signature x is of the same than signature y. Similarity theories would try to calculate how much similar is x with y. Although, we don't know what parts of the signature would be use to create categories, the reciprocal categorization effect theory would start with goal oriented categories such as "*hit, false alarm, correct* *rejection, miss*”, and subcategories of hit, such as “*signatures made in hurry*” and of correct-rejection such as “*perfectly imitated*”. Thus a very dissimilar y can be put with x while another that gets a very high similarity score (z) would be differentiated. In the opposite, imagine the making of a movie with the single shot of the well-known signature (x) made in hurry (y) by a celebrity, and its perfect imitation (z) done by the hand of an actor. The moviemaker could retain signature z while the banker would reject it.

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