WHAT'S THE SCOPE OF THE NAMING GAME? CONSTRAINTS ON SEMANTIC CATEGORIZATION

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Abstract

The *Naming Game* (NG) has become a vivid research paradigm for simulation studies on language evolution and the establishment of naming conventions. Recently, NGs were used for reconstructing the creation of linguistic categories, most notably for color terms. We recap the functional principle of NGs and the latter Categorization Games (CGs) and evaluate them in the light of semantic data of linguistic categorization outside the domain of colors. This comparison reveals two specifics of the CG paradigm: Firstly, the emerging categories draw basically on the predefined topology of the learning domain. Secondly, the kind of categories that can be learnt in CGs is bound to context-independent intersective categories. This suggests that the NG and the CG focus on a special aspect of natural language categorization, which disregards context-sensitive categories used in a non-compositional manner.

1. Motivation

The paradigmatic model of the evolution of natural language semantics is the *Categorization Game* (CG). We believe that the CG is a powerful account for the constitution of categories within agents, which is of great importance for linguistics and cognitive sciences. In this paper, we take a *semantic perspective* on the relation between the elements in the agents' lexica and the things these agents talk about, that happen to be colors. Taking a semantic stance, however, color predicates (i.e. the elements of the agents' lexica) are examples of but one out of various *kinds* of semantic predicates. To be more concrete, they are extensional and intersective. Since the majority of linguistic predicates is of a different kind, this suggests a *semantic* restriction of the CG. Since we talk about predicates of a different semantic *kind* (not of other predicates of the same kind), adding more simulation parameters or syntactic combination rules will probably not suffice to provide a semantic extension of the CG.

Our semantic assessment is based on the "semantic range" of categorization as documented in pertaining publications. We do not want to blame either quoted or not quoted authors. We think that the success of the CG even strengthens the need for a critical assessments not only of its current achievements (documented by a growing number of publications), but also of its possible shortcomings. It is this latter aspect that we want to bring up for discussion.

2. Introduction

The *Naming Game* (NG) has been used in order to simulate, model, reconstruct or predict different linguistic phenomena. We distinguish the following three variants:

- *Conventions.* The focus here is on how naming conventions evolve without explicit agreement between language users. Agents, modeled as word-object "mapping systems", converge onto the same mappings between words and objects. Note that although both sets involved are called "words" and "objects", the NG is independent of the kind or provenance of the elements to be conventionally associated.

- *Language Evolution.* The focus here is on how the members of a population come to develop a shared vocabulary (a "language") and how this language changes within the same generation (intra-generational change) or over various generations of agents (inter-generational change).

- *Categorization.* Recently, the NG has been played in a variant called *Categorization Game* (CG) that deals with perceptual categories. Perceptual categories are modeled as cognitive units that emerge in perceptible environments (Puglisi, Baronchelli, & Loreto, 2008). CGs enable the study of how linguistic categories emerge out of an interaction of perception and communication.

Despite the success of the NG in all these areas, we believe that its focus on a special class of predicates hinders it from being an encompassing model of predication. We shed light on this class of predicates mainly by example of the *Categorization Game* (CG). This is done as follows: in its simplest case (Section 3), the NG is shown to deal with words in the role of individual constants, so that it disregards predicates. CGs are capable of accounting for monadic categories, that is, properties in logics. However, in a stepwise argument we show (1) that CGs cannot readily go beyond properties (Section 4.1); (2) that CGs model context-independent categories (Section 4.2); and (3) that CGs are bound to intersective compositionality (Section 5). The class of categories of context-independent intersective properties is not representative for the majority of categories. Since the NG focuses on this *subset of natural language categories*, it appears to be a model of a special case of linguistic categorization rather than of the rule.

3. On the Core of the Naming Game Paradigm

The key ingredients of a *Naming Game* (NG) are a set of strings $\mathcal{W} = \{w_1, \ldots, w_m\}$ – henceforth called *words* – and a set of objects $\mathcal{O} = \{o_1, \ldots, o_n\}$, that is, the *meanings* of the words. A standard assumption that underlies the NG is that objects can be any kind of entities as, for example, concrete objects, relations, or situations (Baronchelli, Felici, Loreto, Caglioti, & Steels, 2006, p. 3). The strings can be sequences drawn from a finite alphabet (Steels & McIntyre, 1999) or terminal symbols that are output by a grammar (Hashimoto, 1997). A third ingredient is the set of agents $\mathcal{A} = \{a_1, \ldots, a_o\}$ whose elements are defined as subsets of $\mathcal{W} \times \mathcal{O}$ and whose projection onto the set of words is called *agent lexicon* $L(a_i)$, $a_i \in \mathcal{A}$. In the simplest case, agents are just functions from words to objects – cf. (Steels, 1995), where "A language $L = W \times M$ is a set of one-to-one mappings between words and meanings." See Baronchelli et al. (2006) for the interaction scheme by which a single round of the NG is played.

The ingredients of NGs have been enhanced in various ways. One variation is to account for frequencies of word-object mappings, another one is to take polysemy, homonymy (Steels & McIntyre, 1999) or synonymy (Baronchelli, Loreto, & Steels, 2008) into acount.

In any event, the *semantic* core of the NG can be captured by the following *Kernel Function of the Naming Game* (KFNG):

KFNG: Kernel Function of the Naming Game Agents $a \in \mathcal{A}$ correspond to *interpretation functions* $I_a : \mathcal{W} \to \mathcal{O}$ such that $\forall w \in L(a)$: $I_a(w) \in \mathcal{O}$. That is, for any agent, each word has exactly one meaning that equals a single object of the domain of objects. Seen from a logical point this is tantamount to individual constants (Gamut, 1991a, p. 65). Thus the semantic kind of the words that agents learn in a NG is that of *individual constants*.

The notion of individual constants is far too restricted when it comes to learning *predicates* that denote n-place relations. Look, for example, at the learning of a color term like *red*. If such a predicate would be treated as a proper name, it would be impossible to express that one object has a different shade of red than another or that different objects are equally red. It would even be impossible to predicate *of* an object that it is red at all. This is obviously not the way *red* is used in a natural language. Instead, a word like *red* is required to be a *predicate*, that is, to be a kind of expression that takes an argument, i.e., to be of arity 1 – in contrast to its treatment as an individual constant, that is, a function of arity 0. This approach fails to account for the application of predicates (of whatever arity > 1) onto individuals, that is, for the description of situations or events (Chierchia & McConnell-Ginet, 2000, p. 59). See, however, the claim of

Baronchelli et al. (2006, p. 3) according to which objects in a NG can be of a wide range of ontological provenance including individuals, properties, relations, situations and events. Our analysis of *red* suggests instead that words denoting properties are of a different *semantic* kind than names of individuals and therefore have to be modeled in a different way (Frege, 1891) – likewise for relations, situations and events. One may argue that this means to misunderstand the assumption of Baronchelli et al. (2006) who treat relations as complex objects of which words are predicated as properties. However, such an approach would neglect the basic semantic difference between names and predicates.

This does not mean, however, that it would be impossible to build CGs of more levels of predication. Seemingly, what is lacking on that account is a kind of abstraction that leads to relation-valued interpretation functions $I_a(w) \subseteq \mathcal{O}^n$. that in the case of polysemous predicates of arity $n = 1$ become set-valued. Under this regime, a word $w \in \mathcal{W}$ can be treated semantically as a predicate of a certain arity that can be applied to its arguments.

The next section discusses CGs as a variant of the NG that are based on set-valued interpretation functions in order to study the formation of color categories. We show that this variant is still restricted to a subset of predicates.

4. The Semantic Scope of the Categorization Game

CGs are usually played within the domain of colors. The object domain is made up of a continuum of wavelengths – mapped onto the interval of real numbers $[0, 1)$ – that is partitioned by agents into perceptual categories. The color domain is used to show how discrete linguistic categories emerge out of an interaction of perception and communication (Puglisi et al., 2008, p. 7936, p. 7939); see also (Steels & Belpaeme, 2005; Baronchelli et al., 2006). For the rules of the CG see Puglisi et al. (2008, Supporting Material).

A CG, like any language game, "requires discrimination and interpretation as well as production and parsing." (Steels, 2005, p. 220). A CG also involves category learning, since this is the goal of the game. All in all, three semantic ingredients are given in a single round of a CG:

1. *Predication.* Agents transmit words in order to communicate about the objects presented in a CG round. They also use pointing gestures to single out objects (Puglisi et al., 2008).
2. *First Order Categorization, or Discrimination.* Agents categorize objects according to their categorization scheme currently in force: a given object is *discriminated* by means of a perceptual category

(Steels, 1996; Puglisi et al., 2008), that is, by a judgement of the sort $o \in [\![C]\!]$.

3. *Second Order Categorization, or Learning* relates to the extension of categories, that is, the composition of $[\![C]\!]$ as a set. We deal with the kinds of categories that can be learnt in a CG in Section 5.

Since perceptual categories are defined as sets of objects, it follows that word meanings are exclusively modeled as sets of objects. Thus, CGs ground in an *extensional semantics*. Furthermore, predication and first-order categorization are intertwined in a Tarskian manner (Tarski, 1935): a predication can be true or false, depending on whether the object in question is an element of the category tied to the predicate in use. The functional principle of the CG can now be summarized as follows:

KFCG: Kernel Function of the Categorization Game Agents $a \in \mathcal{A}$ are interpretation functions $I_a : \mathcal{W} \mapsto \wp(\mathcal{O})$ such that

- $\forall w \in L(a) : I_a(w) \subseteq \mathcal{O}$. Initially, $I_a(w) = \mathcal{O}$.[a]

The interpretation function of the CG captures predication by the following Tarski-style semantic rule:

- an object o falls into a's perceptual category c denoted by w_c iff $o \in I_a(w_c)$.

In what follows, we hint at two restrictions of this model of perceptual categories: CGs are limited to properties (Section 4.1) and to context-independent categories (Section 4.2).

4.1. *Topology-related Restrictions*

Perceptual categories are supposed to be *non-overlapping* and *contiguous* subintervals of $[0, 1]$ – see, for example, Puglisi et al. (2008). These assumptions have three implications:

1. The notion of non-overlapping categories contrasts with the notion of prototypes (Rosch, 1978). In order to circumvent this contrast, one needs to account for fuzzy categories that can overlap.

2. Categories are never made up of non-adjacent subintervals. Actually, there are perceptual categories that are constituted in a discontinuous way. In the case of colors think of dyschromatopsia, where the non-contiguous intervals of red and green are grouped into one category.

[a] This approach implements a Platonic prior knowledge of agents about the color space as it predetermines the identity of the category domain. Further, the initial condition $I(w) = \mathcal{O}$ is related to a second-order predicate *color* as in *blue is the color of the sky.*

3. Categories are limited to sets of objects, that is, to properties. Thus, n-place relations like *between*, *give* or *preceding*, that require to be sets (of n-tuples) from $\wp(\mathcal{O}^n)$, $n > 1$, cannot be captured readily.

In the next subsection we argue that the properties that are learnable by CGs belong to the class of context-independent properties.

4.2. *Gradable Properties*

Prima facie, the CG fits perfectly to the domain of gradable properties like sizes (Steels, 1996, p. 338). As a result of size-related CGs, size intervals are segmented by agents into perceptual categories as the meanings of words like, say, "small", "large" and "giant". Any object that is an element of the partition denoted by *small* is classified as being of small size, *irrespective of its other properties.* However, in natural languages things are categorized as small or big in relation to a *tertium comparationis* – cf. Aristotle's discussion of the category of *quantity* (Aristoteles, 1998). Instead of being independently given sets of objects, size categories are *subsets* of their comparison class, i.e., they are *subsective* (Chierchia & McConnell-Ginet, 2000, p. 465). This suggests that CGs model properties, which in the latter sense are context-independent. Since CGs deal with single quality dimensions (Gärdenfors, 2000), this restriction might be justified, but to the cost of limiting the semantic scope of the game to a certain class of categories. A compositional approach, however, should allow for cross-categorization. Accordingly, we finally look at a compositional variant of the CG and show that it is bound to intersective predicates.

5. Compositionality

A compositional extension of the CG has been devised by Vogt (2005). Here, learning takes place in a 4-dimensional color-shape space, the *conceptual space* **rgbs**, where the color partition is modeled as a 3-dimensional **rgb** space. Each dimension of the conceptual space is partitioned into categories according to a number of categorical features playing the role of prototypes (Vogt, 2005, p. 214). A category is modeled as a 4-dimensional vector where each slot represents a certain quality dimension. An agent categorizes an object according to its "private ontology $\mathcal{O}_a$" (Vogt, 2005, p. 214) "by taking for each [object] feature $f_{i,j}$ the categorical feature $c_i \in \mathcal{O}_a$ nearest to $f_{i,j}$, and then combining each dimension to form the category $\mathbf{c}_j = (c_1, \ldots, c_n)$." (Vogt, 2005, p. 215). That is, partitions of the object space $\mathcal{O}_a$ are derived from partitions of the underlying spaces of quality dimensions whose partitions are independent of each other. Let us denote such a feature-related partition by $S(c_i)$ where c_i, $i \in \{1, \ldots, n\}$, is a prototypical feature. Now, if an object o is of category c_i we can write $o \in S(c_i)$ by analogy to one-dimensional CGs. Further, a statement of this sort is independent of any other statement $o \in S(c_k)$ for which $k \in \{1, \ldots, n\} \setminus \{i\}$. An object o belongs to $\mathbf{c}_j$ iff $o \in S(c_1) \wedge \ldots \wedge o \in S(c_n)$ iff $o \in S(c_1) \cap \ldots \cap S(c_n)$. Thus, this compositional extension of the CG is an *intersective* one (Chierchia & McConnell-Ginet, 2000, p. 459). It cannot deal with subsective predicates like (1) size terms as, for example, in *giant midget*, (2) with non-predicational predicates (e.g., *alleged*, *former*) (Chierchia & McConnell-Ginet, 2000, p. 459), and (3) with predicates that include semantic calibration (as necessary, e.g., for dealing with combinations like *stone lion* or *toy airplane* (Kamp & Partee, 1995)). This suggests that the kind of categories learnable by the KFCG is limited.

6. Conclusion

A compound predication like *x is a P Q* has to be modeled by creating a new complex predicate PQ instead of just building the conjunction $P \wedge Q$ (Gamut, 1991b, pp. 77f). The potential to enter into the formation of a new predicate is not possible, however, if the categories denoted by P and Q are fixed in terms of sets of objects. The enhancement necessary for dealing with the relational character of categories is to incorporate a mediating level between $\mathcal{O}$ and $\mathcal{W}$ – that is, to introduce *intensionality.* The need to distinguish three semiotic levels, viz. object, concept and symbol as connected in a semiotic triad, has already been advocated by Steels (2008, p. 224). Furthermore, in order to account for symbolic representations, one has to provide some modeling means for "how the expression of different meanings can be combined to create compositional representations" (Steels, 2008, p. 232). Accordingly, Steels and colleagues (Steels & De Beule, 2006a, 2006b) implement a grammar formalism, called *Fluid Construction Grammar* (FCG), capable of *representing* compositional constructions of (presumably) all kinds.However, as Steels (2008, p. 227, p. 237) notes, using prefabricated meaning representations does not answer the question about the evolution of categorization and categories. Thus, there is a missing link between compositional representations on the one hand and the genesis of the represented categories on the other hand. Thanks to the CG, this link is given for extensional, intersective categories like color categories. However, even in the domain of perceptual categories, so runs our argument, there is a range of semantic kinds of categories that seem to be outside the scope of current simulations.

References

Aristoteles. (1998). *Kategorien, Hermeneutik.* Hamburg: Meiner. (Translated by Hans Günter Zekl)

Baronchelli, A., Felici, M., Loreto, V., Caglioti, E., & Steels, L. (2006). Sharp transition towards shared vocabularies in multi-agent systems. *Journal of Statistical Mechanics: Theory and Experiment*, *2006*(06), P06014.

Baronchelli, A., Loreto, V., & Steels, L. (2008). In-depth analysis of the naming game dynamics: the homogeneous mixing case. *International Journal of Modern Physics C*, *19*(5), 785–812.

Chierchia, G., & McConnell-Ginet, S. (2000). *Meaning and grammar – an introduction to semantics* (2 ed.). Cambridge: MIT Press.

Frege, G. (1891). *Funktion und Begriff.* Reprinted in ? (?, p. 2–22).

Gamut, L. T. F. (1991a). *Logic, language, and meaning* (Vol. 1: Introduction to Logic). Chicago: The University of Chicago Press.

Gamut, L. T. F. (1991b). *Logic, language, and meaning* (Vol. 2: Intensional Logic and Logical Grammar). Chicago: The University of Chicago Press.

Gärdenfors, P. (2000). *Conceptual spaces.* Cambridge, MA: MIT Press.

Hashimoto, T. (1997). Usage-based structuralization of relationships between words. In P. Husbands & I. Harvey (Eds.), *Proceedings of the fourth european conference on artificial life* (pp. 483–492). MIT Press.

Kamp, H., & Partee, B. (1995). Prototype theory and compositionality. *Cognition*, *57*(2), 129–191.

Puglisi, A., Baronchelli, A., & Loreto, V. (2008). Cultural route to the emergence of linguistic categories. *PNAS*, *105*(23), 7936–7940.

Rosch, E. (1978). Principles of categorization. In E. Rosch & B. B. Lloyd (Eds.), *Cognition and categorization* (p. 27-48). Hillsdale, N. J.: Erlbaum.

Steels, L. (1995). A self-organizing spatial vocabulary. *Artificial Life*, *2*, 319–332.

Steels, L. (1996). Perceptually grounded meaning creation. In *Proceedings of the second international conference on multiagent systems* (pp. 338–344). Kyoto.

Steels, L. (2005). The emergence and evolution of linguistic structure: from lexical to grammatical communication systems. *Connection Science*, *17*(3–4), 213–230.

Steels, L. (2008). The symbol grounding problem has been solved. So what's next? In M. de Vega, A. M. Glenberg, & A. C. Graesser (Eds.), *Symbols, embodiment and meaning* (pp. 223–244). Oxford, NY: Oxford University Press.

Steels, L., & Belpaeme, T. (2005). Coordinating perceptually grounded categories through language: A case study for colour. *Behavioral and Brain Sciences*, *28*(4), 469–529. (Target article with open peer commentary)

Steels, L., & De Beule, J. (2006a). A (very) brief introduction to Fluid Construction Grammar. In *Proceedings of the 3rd workshop on scalable natural language understanding* (pp. 73–80). New York City.

Steels, L., & De Beule, J. (2006b). Unify and merge in Fluid Construction Grammar. In P. Vogt, Y. Sugita, E. Tuci, & C. Nehaniv (Eds.), *Symbol grounding and beyond: Proceedings of the third international workshop on the emergence and evolution of linguistic communication* (pp. 197–223). Rome, Italy.

Steels, L., & McIntyre, A. (1999). Spatially distributed naming games. *Advances in Complex Systems*, *1*(4), 301–323.

Tarski, A. (1935). Der Wahrheitsbegriff in den formalisierten Sprachen. *Studia Philosophica*, *1*, 261–405.

Vogt, P. (2005). The emergence of compositional structures in perceptually grounded language games. *Artificial Intelligence*, *167*(1–2), 206–242. (Connecting Language to the World)