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Dissortativity in a Bipartite Network of Dependency Relations and Communicative Functions

Abstract: This paper investigates the relation of syntax and communicative functions. We contrasted Dependency Grammar (DG) that sees syntax as autonomous and independent of its possible communicative uses with Construction Grammar (CxG) that maintains that the building blocks of language are stored form-meaning pairings, including phrasal patterns which may be associated with particular communicative or discourse functions. We constructed two treebanks of Hebrew, of parental speech and of young children's speech, parsing the sentences for DG and coding them for the communicative function of the utterances. The communicative-syntactic system is modeled as a bipartite network of verb-direct object (VO) combinations and of communicative functions (CF). DG predicts that VO-CF matching be scale-free, whereas CxG predicts that the matching is one-to-one. Next, we analyzed the degree of assortativity of the VO-CF bipartite network. We calculated a Pearson's correlation coefficient between the degrees of all pairs of connected nodes, predicting a positive assortativity on CxG and a negative one, on DG. The results do not support the concept of holistic constructions fusing syntactic structures and communicative functions. Instead, the communicative-syntactic system is a complex system with sub-systems mapping onto one another.

Keywords: communicative functions, constructions, bipartite network, assortativity

1 Introduction

The purpose of this paper is to find out how syntax and communicative functions are related in parental speech and in young children's speech. This question has important implications for theoretical linguistics as well as for a theory of language acquisition. Theoretical linguistics in its orthodox version sees

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syntax as autonomous and independent of its possible communicative uses (Chomsky 1988, Saussure 1922/1983), essentially leaving the question open how the one maps onto the other. This conception is adopted by the various versions of the Chomskian tradition as well as many other theories of grammar, among them Dependency Grammar (DG; Tesnière 1959), which is the framework of choice of the present study.

In sheer contrast, a contemporary theory, Construction Grammar (CxG), maintains that the building blocks of language are stored form-meaning pairings, with forms including morphemes and words but also phrasal, clausal or sentence patterns all of which are said to be associated with particular semantic, pragmatic, communicative or discourse functions (Fillmore 1988; Goldberg 2003). In conservative versions of the theory, for example the one developed by Goldberg (1995), syntactic relations are acknowledged, albeit re-defined as constructions. That is, some constructions consist of words in a particular syntactic relation such as verb-object, which is then claimed to possess a prototypical meaning with which it is associated. In an extreme version of this theory, Radical Construction Grammar (Croft 2005), it is, however, claimed that there are no syntactic relations such as dependency between words of a sentence, only part-whole relations by which words or sequences of words contribute to the sentence's communicative meaning. This approach rejects formal grammars such as DG on the grounds that they consist of linguistic rules which are merely algebraic procedures for combining words but that do not themselves contribute to meaning, whereas by CxG constructions are meaningful linguistic symbols, being the patterns used in communication. Thus, a linguistic construction is defined as a unit of language that comprises multiple linguistic elements used together for a coherent communicative function, or sub-function such as reference.

To summarize, CxG views the relationship between syntax and communication as a defining association of particular semantic and communicative meanings with certain patterns of surface structure. Which communicative function would be associated with which formal pattern is thought to be determined by the frequency of these patterns in use, hence the so-called "use-conditional" aspect of this theory (Bybee and Hopper 2001).

This theory is particularly influential in the developmental field, giving rise to a model of the acquisition of syntax according to which children do not learn rules for building formal and autonomous structures such as the combination of a verb and a direct object but, rather, they learn the form-meaning pairings of various 'constructions' as the expressions of particular semantic meanings, discourse functions and communicative functions (Ambridge et al. 2015; Gold-

berg 2003; Lieven 2009; Tomasello 2006). Children's language is believed to be especially influenced by the prototypicality or the relative frequency of form-function combinations modelled in the parental speech, so that the expectation is that each communicative function would be associated with a single formal pattern, and this association be "preempted" and "entrenched", that is, resistant to change.

Against this model of grammar and of development, in the present paper we raise the hypothesis that sentences are structured with the syntactic relations suggested by DG (Hudson 1984; Tesnière 1959), and that children learn how to produce head-dependent combinations on the basis of the parental speech that serves as input to their learning. According to our hypothesis, head-dependent combinations are the building-blocks of sentences, and the latter are expressions of communicative functions. In this approach, we are embracing the theoretical stance that syntax is autonomous, and that, potentially, any particular head-dependent combination may be used in a sentence serving any communicative function. The detail of how the one is mapped to the other is an open question which we are approaching in the reported study.

The topological character of language that emerges from CxG differs in a crucial manner from that implied by a formal linguistic theory such as DG. Whereas analytic grammars see language as a multileveled complex system, containing separate sub-systems of, among others, syntax and pragmatics (Liu and Cong 2014), CxG sees language as an "inventory of constructions" (Croft 2005; Langacker 1987), each a holistic fusion of form and meaning. In a grammar positing an autonomous syntax, it is an open question how the sub-levels of language are mapped to each other, for example, how are communicative functions mapped to sentences carrying certain syntactic relations, whereas in a grammar positing constructions, form is mapped uniquely to meaning, fused into holistic form-meaning combinations. The overall topological structure of language is accordingly affected. The global structure of a grammar containing an inventory of constructions is a taxonomical network of such fused units, whereas analytic grammars such as DG form multi-leveled complex systems with topological features characteristic of such systems.

These fundamental differences in topological features make it possible to test the two conceptions of grammar against each other. We can ask, are certain syntactic relations uniquely mapped to certain communicative functions and thus form "constructions"? Or, does the relationship of communicative functions and syntactic relations pattern in a manner expected of a complex system?

It is important to realize that not only complexity theory but also theoretical linguistics and philosophy of language on which formal grammars are based,

embrace the definition of language as a system. The names most centrally associated with this idea are Saussure (1922/1983) and Wittgenstein (1953/1978). Wittgenstein, the philosopher, emphasized in his writings the existence of a complex whole within which individual elements (i.e., particular words or sentences) are meaningful. Language, he pointed out, is similar to a game such as chess, where the existence of the complete game with its set of rules and options is what gives significance to individual moves or pieces. Saussure, the linguist, emphasized the types of connections existing among linguistic units, the interrelations that turn language into a system. His argument for treating language as a system is the dependence of meaning or 'value' of individual words on other words, whether words that occur as their alternatives in sentences, or words that occur together with them, building the structure of sentences. This vision contrasts with CxG's suggestion that language is an "inventory of constructions", namely, a list of units of various sizes; these units may stand in a part-whole relationship with each other but otherwise the inventory is a mere catalogue or collection. These linguistic-philosophical differences appear at first glance to be too abstract to be translated to testable hypotheses. However, with the proper quantitative methods, we can decide between the two conceptions.

We have conducted a study to explore syntax-communications relations both in child-directed adult speech and in young children's speech in order to test the alternative hypotheses regarding the characterization of grammar. We have assembled a large corpus of Hebrew-language spoken utterances produced in the context of parent-child interaction, parsing the sentences for syntax and coding them for the communicative function of the utterances. These data will serve for building two networks representing, respectively, parental and child speech. Our plan is to model the communicative-syntactic system as a bipartite network consisting of two general types of vertices: lexical-syntactic forms, and communicative functions. We shall focus on verb-direct object (VO) combinations and will ask how they form a pattern of connections with the speaker's inventory of communicative functions (CF).

As we have said, the theoretical differences between the two theories of grammar can be expressed as differential predictions regarding the quantitative topological features of the syntax-communication networks. The first difference between the theories touches on the distribution of the connections between VOs and CFs. Networks consist of nodes and the links between them, called edges. The degree of a node in a complex network is the number of incoming or outgoing edges. We shall analyze the distribution of the degrees of specific VO combinations, defined by the verb appearing with any direct object, and of the

degrees of specific CFs, encoding the type of talk interchanges the dyads are engaged in. The two theories of grammar have different quantitative predictions regarding the number of links expected for each node, namely, its degree, as well as regarding the form of the degrees' distribution. According to the hypothesis based on CxG, namely, that language is 'constructions all the way down' (Goldberg 2003), and that children learn specific syntactic constructions as expressions of specific communicative functions (Tomasello 2006), we expect that the VO construction as a whole be strongly associated with some specific type of discourse function. That is, the Constructions approach predicts that VOs and CFs be uniquely connected, as constructions are defined by a unique form-function correspondence. If this is not so for VO in general, then this should be true for individual VOs, namely, combinations of specific verbs with an object. The general linguistic theory predicts that we should find such unique connections in parents' speech, but if not in parents' talk, it should be the case at least in young children's speech as they are supposed to learn such associations and to be "entrenched" in them (Tomasello 2003). In more details, our predictions are as follows.

1) We may expect that VO in general should be associated with some particular CF in maternal speech. We already know that VO is somehow problematic as a construction, as it does not appear to have a prototypical semantic meaning associated with it. The virtual impossibility of matching typical or prototypical semantics to the transitive construction has been extensively discussed in the linguistic literature of English, for instance by Givon (1997), and in the developmental context by Sethuraman and Goodman (2004). As for Hebrew, Glinert (1989) says it quite simply: 'There are no recognized semantic criteria as to which verbs take direct objects.' (p. 159).It is possible though that VO is associated not with a particular semantic prototype but with a specific communicative use. If so, we expect to see this unique association in parental speech. CxG does not specify at which level of generality would a linguistic unit be mapped to a unique CF that provides its meaning. To be exhaustive, we shall test the VO-CF mapping both at the level of an abstract schema of VO and at a lexical-specific definition of individual verbs getting a direct object.
2) Second, it is possible that VO in general is not associated with any specific CF in maternal speech but that individual lexically specific VO combinations are. CxG allows into the grammar both such abstract entities as any VO combination, and lexical-specific entities such as a particular verb with any direct object, for example, "*see something*"

(Goldberg, 1995). Again, we could find that such lexical-syntactic forms are uniquely associated with some specific CF, for example, with requests to see (or not to see) some object.

3) Third, it is possible that even lexical-specific VOs are not associated with a unique CF in maternal speech but, rather, with a set of different CFs. The prediction of CxG in this case is that at least in children's speech, the relevant lexical-specific VOs will be uniquely associated each with a single specific CF, the one most frequently used by mothers with this VO.

In summary, on the basis of CxG we expect that at some level, at the least, VOs and CFs will have unique one-to-one associations.

By contrast, formal grammars such as DG make the opposite prediction regarding the quantitative features of VO-CF combinations. Extrapolating from what we know of the language system under DG assumptions, we expect that VO-couplets and CFs form a joint network that will have the typical topological features characteristic of complex networks. Several studies have shown that networks formed by language units, connected by various different linguistic relationships, exhibit the global statistical features characteristic of complex networks. Naturally occurring complex networks possess some generic topological features, regardless of what are the items making up the network (Baraba'si and Albert 1999; Watts and Strogatz 1998). One of the most important statistical features of complex networks, and possibly their defining attribute, is that the number of links connected to a given node is extremely unevenly distributed. A few nodes have a very large number of links, whereas most nodes have only a very few. For this reason, complex systems are said to be *scale-free*, when the meaning of this term is that there is no typical scale for degrees, and they can range from very low to very high. In previous studies, syntactic, semantic, and phonological networks were found to be scale-free (Ferrer-i-Cancho et al. 2004; Steyvers and Tenenbaum 2005; Vitevitch 2005; Cong and Liu 2014). It is thus expected that the degrees of the various CF and VO nodes should have a scale-free, skewed, power-law distribution. Most certainly it is not expected that the degree distributions would look like a representation of a set of one-to-one mappings.

The further difference between the theories is in their in their expectation regarding the *assortativity* of the matchings between particular VOs and CFs. Assortativity is the relative tendency of nodes to be connected to other nodes of similar degree. The Constructions approach claims the connection between each particular VO (form) and its particular CF (meaning) is unique, that is, a VO with a single link is connected to a CF with a single link. The uniqueness of

the linking is established and maintained by a couple of principles posited in the theory, *entrenchment* and *preemption* (Tomasello 2006). Entrenchment is a notion developed within Cognitive Linguistics and it is a synonym for learning through repeated exposure or use. This is the major process through which unique mappings of form to function are said to be established and maintained in both adult and child speech. When some form is frequently used for the expression of a specific meaning or function, an "entrenched" association is set up that can inhibit or block the adoption of alternative expressions of that meaning or function (Langacker, 1987). Preemption means blocking the use of alternative expressions of specific communicative intentions if there is in the speaker's system an established (entrenched) form of expression for that intent (Clark and Clark 1979; Goldberg 2005; Pinker 1984). The expression of that function is said to be preempted by the entrenched form of expression, meaning it takes precedence over the potential alternative form. For our purposes, the two hypothesized processes are equivalent, serving to account for the unique form-function correspondence which is the defining characteristic of constructions.

In a second testing of the alternate hypotheses, we shall analyze the degree of assortativity of the VO-CF bipartite network. Assortativity is the relative tendency of nodes to be connected to other nodes of similar degree. If there is no relation between the degrees, the type of connection is ***neutral***. This means that the mapping is random, and the use of any VO for any CF is determined by their relative frequencies. When there is a positive correlation between the connected degrees, we talk about ***assortative matching***. CxG possess two features that predict assortative matching. First, the so-called "use-conditional" aspect of the theory predicts that in any choice situation, highly frequent patterns be chosen over low frequency ones. This predicts that formal patterns such as VO be matched to highly frequent communicative functions, and communicative functions be matched to highly frequent formal patterns, making for a positive correlation. In addition, the posited uniqueness of form-function mapping at the limit translates to the topological prediction that the matching of CFs and VOs is assortative. After competition is resolved, each CF is expected to possess just one VO form that maps to that kind of communicative function, and each VO is expected to be used for one single communicative function. The preference for – and maybe complete restriction to – matching a CF with a single VO-form expressing it, to a VO with a single function expressed, leads to a positive correlation between the degrees of the VO nodes and of the CF nodes.

By contrast, a complex-systems approach predicts ***dissortative matching*** in which the degrees of connected nodes are negatively correlated, so that a "choosy" VO linked to only a single (or very few) communicative functions, will

tend to be the expression of "promiscuous" CF, that is, CF's expressed with many different VOs. Not as CxG, DG does not posit a unique matching of forms to functions. On the contrary, the fundamental autonomy of syntax and communication which is the backbone of an analytic grammar, makes it the norm that forms will be used for multiple communicative purposes, and functions be expressed by many different forms. This makes it perfectly possible that VOs and CFs be "promiscuous" and have large linking degrees. This by itself does not force dissortative matching on the VO-CF connections; that has a crucial role for the system. The CF-VI nodes and links form a complex system, and such system must have complete connectivity. In a scale-free system, the connections must be dissortative in order not to leave nodes with low degrees isolated from the rest of the network. Would the connection be assortative, the network would be fragmented, with "choosy" CFs expressed by "dedicated" VOs not being connected to the rest. This pattern is similar to those observed in other scale-free complex systems. For instance, in the Internet there is dissortative mixing and especially a strong suppression of edges between nodes of low degree of connectivity, which is said to be at least partly attributed to the avoidance of isolated clusters (Maslov, Sneppen and Alon 2003). Indeed in the Internet there are no isolated clusters, and according to our hypothesis, neither are there any in the syntax-communication network.

It is easy to see that CxG not only makes it possible for the form-function network to be fragmented but it actually necessitates this fragmentation. That is, we expect the pattern of connection between VO-combinations and CFs to consist of individually connected VOs and CFs, and, thus, to be fragmented.

We have, therefore, two strongly contrasting sets of hypotheses regarding the assortativity of the VO-CF bipartite network. The prediction derived from CxG is that the matching of CFs to VOs (and the other way) will be assortative, with a positive correlation between the degrees of the linked nodes. In addition, we can predict that there will be in this network many (and maybe most) linked nodes where the degree of the VO node and the CF node are both 1, as the link is unique. By contrast, the hypothesis derived from the Complex Systems approach predicts that the matching will be dissortative, namely there will be a negative correlation between the degrees of the connected nodes. In addition, we predict that there will be no unique matchings of two nodes both with a degree of 1, as this would fragment the complex network. This prediction is in particular for the parental network; it remains to be seen if young children with their limited lexicon manage to build a completely connected network.

An interesting question we may not be able to resolve is which party does the choosing or constraining in the association of forms and communicative

uses. It is possible to say that certain forms such as particular VO combinations choose what communicative functions they fill readily, and what functions they will find difficult to serve. For instance, we may think such a VO combinations as '*lost something*' will not easily serve such a function as directing hearer's attention to a new perceptual focus, but will be appropriate for such a function as asking for hearer's help. We might look at such constraints from the other direction and say some communicative functions choose certain language forms such as VO-combinations as appropriate expressions of the relevant function; others will not fit the bill. Verbs and their objects have semantic meaning; the relation between semantics and pragmatics is complex and we would probably be better off treating the selection process as a two-sided one.

As for children's early syntax-communication system, the two theories make clearly contrastive hypotheses. According to developmental theories based on CxG (Goldberg 1995; Tomasello 2006), even if the parental input to development does not contain unique form-function mappings, children would still learn such unique mappings in the shape of "constructions". That is, even if lexical-specific VOs are not associated with a unique CF in maternal speech but, rather, with a set of different CFs, the prediction of CxG is that in children's speech, the relevant lexical-specific VOs will be uniquely associated each with a single specific CF, the one most frequently used by mothers with this VO. The alternative developmental hypothesis based on Dependency Grammar is that syntax is autonomous and the mapping of functions to forms obeys the constraints of a complex system. We expect that children learn not an inventory of isolated form-function couplets but, rather, that they learn language as a complex system. This means that we expect children's bipartite VO-CF network to be similar to mothers'. In prior studies of children's acquisition of syntax it was found that young children's syntactic network is very similar to parents' language network in its global features such as a scale-free distribution (Ninio 2006). Our hypothesis is that children's bipartite network of form-function mapping will also be very similar in its global features to mothers' network, namely, scale-free and dissortative.

Despite its theoretical significance for linguistics and language acquisition theory, there has been no empirical research that systematically investigated the relation between syntax and communicative functions. I believe the reason is mostly methodological: the question is too complex to be dealt with by any but the methods of Complexity Science. Even within Complexity Science, there has been no attempt to represent in the same network both syntax and communication. There have been a few projects modeling syntactic networks, most notably by Ferrer-i-Cancho et al. (2004) and by Cong and Liu (2014), and some

work on semantic networks, for example by Liu (2009), but no attempt yet to model communicative networks, as far as we know. Such a combined language network as the one we are proposing to construct and analyze, will thus constitute an innovation for Complexity Science as well.

The rest of this manuscript will introduce in Section 2 the preparation of two dependency treebanks of spoken Hebrew, and coding for communicative function. Section 3 presents the results of the network analysis and discusses its significance for linguistics and developmental theory. The last section, 4, is the conclusion.

2 Methods and Materials

2.1 Preparation of Two Dependency Treebanks of Spoken Hebrew

In a previous phase of this study, we prepared two dependency treebanks of spoken Hebrew: of adult child-directed speech and of young children's speech. We assembled a large corpus of Hebrew-language spoken utterances produced in the context of parent-child interaction, parsing the sentences for dependency syntax and coding them for the communicative function of the utterances. These data will serve for building two complex networks representing, respectively, parental and child speech.

Speech samples were taken from a videotaped observational study. Forty-eight dyads of mothers interacting with young children acquiring Hebrew as their first language were observed and videotaped in free interaction sessions for 30 minutes at a time in their homes, while engaged in activities of their choosing. The study resulted in 82.5 hours of observations and recorded speech. There were 47 hours of observation of mothers with a high level of education (15 years or more), and 35.5 hours of observation of mothers with a low level of education (up to 10 years). The children in half of each subsample were males, half females, between 10 and 32 months of age, average age about 22 months. The utterances were coded for communicative functions, and parsed for syntactic relations.

Utterances by different mothers in the sample and over different observational periods were pooled. The maternal corpus is considered to give a representative sample of adult speech heard by Hebrew-speaking children at the relevant age-group. The pooled child corpus is representative of young children's earliest multiword speech.

The corpora of spoken sentences were parsed manually for syntactic structure. We based our dependency analyses on Hudson's Word Grammar (Hudson 1984). We also consulted descriptive grammars of Hebrew such as Glinert (1989) and Ornan (1979).

2.2 Coding for Communicative Functions

All multiword expressions were coded for the type of social-communicative function performed in uttering the utterance, using a detailed category system (Ninio and Wheeler 1987). This system is a reasoned taxonomy of verbal-communicative acts, based on Speech Act Theory (Searle 1969), sociological studies of face-to-face interaction (Goffman 1953), and conversational analysis (Sacks, Schegloff and Jefferson 1974). The taxonomy distinguishes 110 different communicative functions applying to stretches of talk Goffman calls talk interchanges. They fall into families of different types: action negotiation, discussions of joint focus of attention, discussions of nonpresent topics, markings of events, performances of moves in game formats and clarification episodes. The interchanges are further distinguished according to the type of interactive state or event they are related to: for instance, negotiations can be of entering into copresence or of leaving, of getting into focused interaction or of leaving it, of initiating joint action or ending it, of performing single acts or of stopping acts in progress. For example, the taxonomy has five different codes for the initiation of a joint activity, defining the communicative function on a considerable level of detail. The functions distinguished are to initiate a new activity by proposing a specific activity; to initiate a new activity by proposing the performance of a move of that activity; to initiate a new activity by proposing the performance of a preparatory move of that activity; to get hearer to start a new activity after activity has been negotiated; and to initiate a new activity while letting hearer propose the activity. Similar high levels of detail are used for distinguishing other types of functions, e.g., performing moves in different interactive games.

Determination of the communicative function of an utterance was done on the basis of the verbal and nonverbal interactive context of the utterance, as judged from the videotaped observations. Coding was aided by considerations of the participants' nonverbal behaviour, by further clarifications put on the utterance, and by the future course of the conversation.

Coding was done by two, highly trained, coders. On the first run through the data, each coder coded half of the corpora. Five complete observational sessions were randomly chosen to undergo blind recoding. On the 2,934 utterances in this corpus, the overall inter-coder agreement was 85.1% (*kappa* value

81.1). Subsequent to the reliability check, the data was run through a second time, each coder checking the work of the other. All disagreements were discussed and reconciled.

In this study, only spontaneous utterances were included; we excluded utterances where the function was to imitate a previous utterance, to recite texts of books, poetry or lyrics of songs; or else to complete words and texts on demand. In the maternal corpus there were 61 different communicative functions expressed; in the child corpus, 38.

3 Results and Discussions

The maternal corpus contained 14,036 sentences expressing VO relations. The child corpus consisted of 2,244 sentences with VO.

For statistical analysis, verbs heading VO combinations were classified into verb-stem groups or lemmas by their consonantal root and verb-pattern (*binyan*) value. This analysis discounts tense, gender and plural inflections, and retains the semantic meaning of the verbs. In English this would mean that '*walks*' and '*walk*' are treated as an identical lemma. Tense, gender and number were not seen as relevant for the use of a syntactic combination for communication.

We modelled the communicative-syntactic system as a bipartite network consisting of two general types of vertices (nodes): on the one side, lexical-syntactic forms consisting of VO combinations with specific verbs getting a direct object, and on the other side, the communicative function (CF) of the sentence in which the VO occurred. The links (edges) between the nodes represent speech events in which such an association between form and function occurred. We focused on types of connections and disregarded their token frequency; namely, a link marks the fact that at least one such form-function connection has been observed in the data.

We shall analyze the topological features of the network of connections in the bipartite graph of VO-CF. The relevant measurements are probing the global structural properties of the network. First, we shall analyze the network generated from adult speech, namely, mothers' child-directed speech. This kind of talk is considered the linguistic input for children's acquisition of syntax. Then, we shall analyze children's network, to explore the features of the output of the learning process.

3.1 Form-function Mapping in Maternal Speech

First we tested the alternative form-function hypotheses on adult speech, more particularly, mothers' child-directed speech.

3.1.1 Unique Mapping or Scale-free Mapping

As CxG does not specify at which level of generality a linguistic unit is mapped to a unique CF that provides its meaning, we have tested the hypotheses regarding VO-CF form-function mapping both at the level of an abstract schema of VO and at a lexical-specific definition of individual verbs getting a direct object.

The first possibility derived from CxG is that the multi-word surface structure we call VO is a kind of abstract schema with the features of a construction. As constructions are defined by a unique form-function correspondence, this predicts that adults use the VO construction in general for the expression of some specific type of communicative function. That is, any kind of VO should be uniquely connected to some specific CF, with a degree of 1 in the bipartite network.

Testing this hypothesis, we counted the number of different CFs linked to maternal VOs. The findings were that mothers use the VO pattern for 61 different CFs, not for a single CF. It is obvious that the abstract syntactic pattern of VO as a whole is not uniquely associated with a particular communicative function in the linguistic input. Instead of a single specific CF, mothers use the VO pattern for the maximal number of communicative functions in their repertoire.

The alternative hypothesis derived from DG is that VO as a structural entity be mapped to communicative uses in a scale-free manner. If the prediction of the Construction approach is that the connection of VO and CF is unique, the prediction from DG is that the mapping between the two types of nodes is not characterized by any specific value; the degrees are supposed to be distributed by a function such as power-law.

The second option derived from CxG is that not the complete abstract schema but each specific VO is associated with a unique CF. The bipartite networks constructed had 294 nodes for VOs, 61 nodes for CFs and 1405 edges.

There were 294 different verbs used in the VO pattern in maternal speech. The prediction was that each particular verb occurring with a direct object will be uniquely associated with a single function, that is, its degree in the bipartite network will be 1. According to this hypothesis, there should be at the most 294 different types of VO-CF combinations. In actuality, there were 1,405 different combination of VO and CF. We computed the degrees of different VO nodes, that

is, the number of different communicative functions each served. Fig. 1 presents the distribution of the degrees of specific VOs, in mothers' speech.

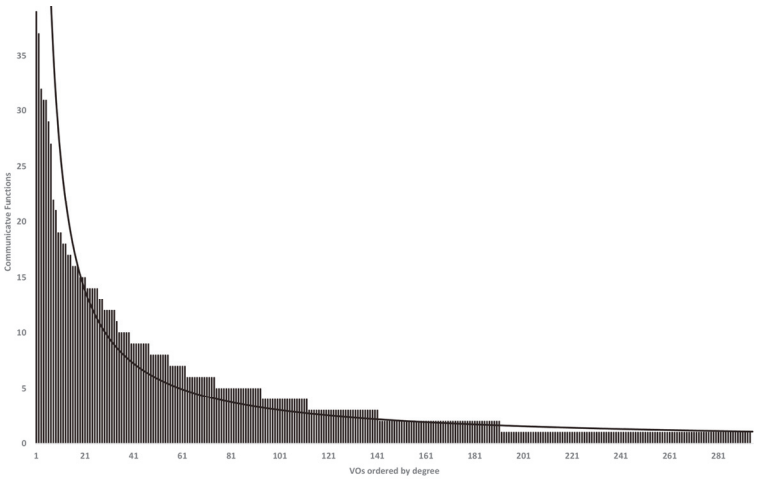

Fig. 1: Distribution of degrees of VO nodes defined by the verb heading the combination, in the bipartite network with CFs, in mothers' speech, with power-law trendline added

We fitted a power-law trendline to the graph, using the option provided by the Excel program. The function was:

$$y = 263.15x^{-0.968} \quad (1)$$

and the fit was R^2= 0.904. That is, the distribution of connectivities of the VO nodes in the bipartite network with CFs is extremely broad, in fact scale-free, and most certainly not unitary.

To summarize, in the first place we tested the radical possibility derived from CxG that all VOs serve a single identifiable CF. This hypothesis was rejected. In the second place, we tested the hypothesis that individual, lexically specific VO combinations – defined by being headed by a particular verb -- are uniquely associated each with a single CF in maternal speech. This lexical-specific constructions hypothesis was rejected, too.

3.1.2 Assortativity

In further testing of the alternate form-function mapping hypotheses, we shall analyze the *assortativity* of the VO-CF bipartite network. We shall calculate assortativity by the Pearson's correlation coefficient between the degrees of all pairs of connected nodes (Newman 2002).

There are three options: assortativity is neutral, positive or negative (dissortativity). Neutral assortativity means connections are random and are not influenced by the degree of the node connected to. Positive assortativity means a node with high connectivity will be connected to nodes of high connectivity, and nodes with low connectivity, to nodes of low connectivity. In our case, VOs with many functions (namely, promiscuous VOs) would connect to functions with many VOs (namely, promiscuous functions), and VOs with few functions (namely, choosy ones), to functions with few VOs (namely, choosy ones). If the mapping is one-to-one as expected by the Construction approach, this would mean all VOs and all FCs are choosy, and the assortativity is positive.

In the case of dissortativity, high-connecting VOs would connect to low-connecting functions, and low-connecting VOs, to high-connecting functions. If there are extremely choosy VOs or FCs, with a single linked node of the opposite kind, the prediction based on formal grammars would be that these are linked to promiscuous nodes. The reason is that one-to-one linking would generate fragmentation, with individual linked nodes being separated from the rest of the system. A formal grammar predicts that the bipartite network of VOs and CFs is a complex system, namely, it is totally connected. That implies dissortativity.

There were 1,405 different combinations of CFs and VOs. We computed a Pearson correlation coefficient between degrees of linked CF and VO nodes; the coefficient was −.43 with 1,403 degrees of freedom. This value is significant at the $p < 0.001$ level.

That is, in mothers' network of form-function mapping, we found dissortativity (negative degree correlations), and it is as predicted by a formal grammar such as Dependency Grammar, not as predicted by Construction Grammar. There are many different possible explanations for dissortativity (for instance, see Maslow and Sneppen 2002). We tied the possible dissortativity of the network to the suppression of low-connectivity nodes with one link avoiding links to low-connectivity nodes of the opposite type, also with one link. We derived the prediction that the bipartite network of syntax and communication be dissortative, and unique mapping be avoided, from the need of language networks to be all-connected. A similar explanation for the strong suppression of connections between pairs of nodes of low connectivity was offered for the dissortativi-

ty of the Internet (Maslov, Sneppen and Zaliznyak 2004), as the Internet operates under the constraint that clusters of autonomous systems do not stay isolated from each other but have to be connected to other parts of the net by at least one path. In a less obvious way, language also operates under the constraint that it be completely connected. We heard from Wittgenstein (1953/1978) and Saussure (1922/1983) that language is a system and that meaningfulness is achieved by contrast. We can operationalize this very general concept to the requirement associated with complex systems, namely complete connectivity.

To test if this explanation is correct, we checked if indeed there was complete connectivity in the bipartite network connecting the syntactic pattern VO to communicative uses. To achieve connectivity in a bipartite network, there cannot be isolated couplets where a given VO is linked to only a single CF, and that CF is only linked to that VO. Checking the data, there were 103 VO types with only a single CF, but in none of the cases was that function used only with the relevant "choosy" VO. Similarly, there were 11 different CFs (18.0% of the inventory) that were expressed by only a single VO, but all these had also several other functions. In the whole network, there was no 1-to-1 mapping at all, thus no isolated VO-CF units. The network has complete connectivity.

It appears that in the syntax-communication system of adult child-directed speech, there is a suppression of connections between nodes with low connectivity. Take note that the expected pattern according to Construction Grammar is one-to-one mapping which we did not find at all in our data. It may be summarized that the maternal network of form-function connections involving the VO pattern does not appear to be composed of constructions, but, rather, of autonomous forms used for a variety of functions, as long as this use does not violate the constraint that the whole network be connected.

We turn now to young children's early syntax-communication system. The hypothesis derived from CxG expect this system to consist of unique form-function mappings, whereas the hypothesis derived from DG expects children's bipartite VO-CF network to be a complex system and similar to mothers'.

3.2 Form-function Mapping in Young Children's Speech

Children use the VO pattern with 38 different CFs, rather than with a single CF. This rejects the extreme hypothesis derived from CxG that the multiword surface structure we call VO is a kind of abstract schema with the features of a construction. As constructions are defined by a unique form-function correspondence, this predicts that children use the VO construction in general for the expression

of some specific type of communicative function. Apparently, VO is not an abstract schema/construction for young children.

Moving on to the second option derived from CxG, each specific VO may be associated with a unique CF. The bipartite networks constructed for children had 127 nodes for VOs, 38 nodes for CFs and 465 edges.

There were 127 different verbs used in the VO pattern in child speech. The prediction was that each particular verb occurring with a direct object will be uniquely associated with a single function, that is, its degree in the bipartite network will be 1. According to this hypothesis, there should be at the most 127 different types of VO-CF combinations. In actuality, there were 465 different combination of VO and CF. We computed the degrees of different VO nodes, that is, the number of different communicative functions each served. Fig. 2 presents the distribution of the degrees of specific VOs, in children's speech.

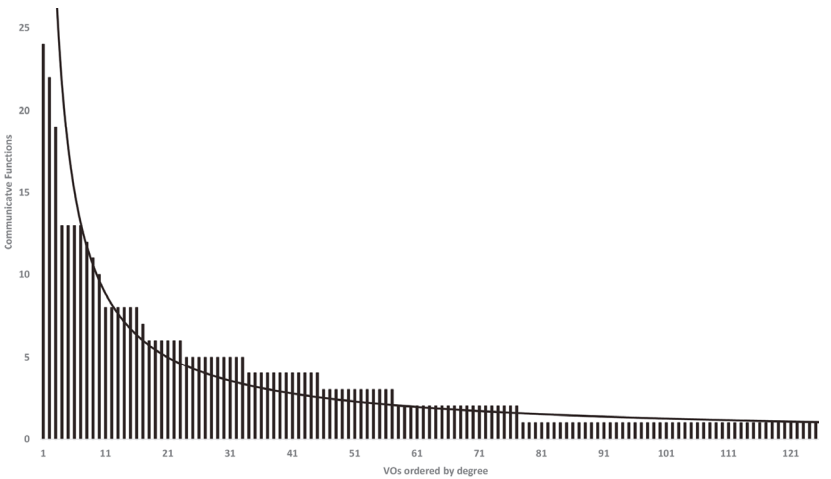

Fig. 2: Distribution of degrees of VO nodes defined by the verb heading the combination, in the bipartite network with CFs, in children' speech, with power-law trendline added

We fitted a power-law trendline to the graph. The function was:

$$y = 73.702x^{-0.884} \tag{2}$$

and the fit was R^2= 0.9046. That is, the distribution of connectivities of the VO nodes in the bipartite network with CFs is scale-free, and not unitary.

The slope of the power law function and its fit are practically identical to mothers'. The similarity of the two graphs is striking, especially if we remember that children have less that half number of different verbs in VO than mothers, and about half as many CFs.

Next, we measured the assortativity in children's network. There were 465 different types of combination of VOs and CFs. The Pearson's correlation coefficient between the degrees of all pairs of connected nodes (Newman 2002) was -0.38 (463 D.F., $p<0.001$), very similar to mothers'.

As in mothers' network, the negative assortativity is connected to avoidance of isolated clusters. There were 50 VO types with only a single CF, but in none of the cases was that function used only with the relevant "choosy" VO. Similarly, there were 10 different CFs (26.3% of the inventory) that were expressed by only a single VO, but all these VOs had additional functions. In the whole network, there was no 1-to-1 mapping at all, thus no isolated VO-CF units. The child network has complete connectivity.

4 Conclusions

Theoretical issues in linguistics such as the relative validity of Dependency Grammar versus Construction Grammar are usually not approached with the tools of the quantitative analysis of syntactic networks. This, however, was the goal of the present paper. By using the tools of statistical physics of complex networks, we validated the use of Dependency Grammar to describe syntactic patterns and showed that Construction Grammar fails to predict the topological features of the syntax-communication network. We also showed that maternal and child syntactic-communicative dependency networks share their major quantitative features such as scale-free degree distributions and dissortative matching of syntactic schemas to communicative functions. We did not find evidence for "entrenchment", "preemption" or any other process that would generate the one-to-one mapping of syntax and pragmatics expected from constructions. The relation of syntax and communication does not consist of a list with entrenched associations between VO-phrases and certain CFs. Instead, we found that both mothers' and children's syntax and pragmatics form a complex system with typical characteristics. First, VO as an abstract syntactic construction does not get used for the expression of a single type of communicative function but, rather, for the expression of many different types of functions. Second, when we look at specific VO phrases defined by the use of particular verbs, we find that syntax and pragmatics form a network with dissortative matching,

mainly because of a significant difference in the numbers of nodes for VOs and CF. In such conditions, dissociative matching is the only way to achieve a completely connected network. Most significantly, the considerable difference in the numbers of specific nodes for VOs and CFs is part of the findings, namely, that the mapping between syntax and pragmatics is not one-to-one but a complex many-to-one and one-to-many mapping between syntactic types and communicative types. We have also shown that children learn the global features of the system very early on; what is left to learn is more of the concrete linguistic items constructing the system: young children possess fewer verbs in the VO pattern and fewer CFs than there are in mothers' speech.

One alternative we need yet to discuss concerns the possibility that VOs fulfill not complete communicative functions but, instead, sub-functions which are components of many different communicative functions. Tomasello (2006) gives NP as an example of a phrase filling such a sub-function, pointing out that, regardless of its specific composition, a NP always serves to make reference. Although this claim is not quite correct (there are NPs that serve as predicate complements without referencing any specific entity), it is worth examining in more detail. Tomasello gives NPs as an example of a phrase serving a subfunction with a wide spread in different communicative functions, with other types of phrases evidently behaving similarly and filling other kinds of subfunctions. The question is, if NPs fill sub-functions, why not VOs also? The answer is that, besides VO, there are many different verb-based argument structures, for instance verb-indirect-object, verb-prepositional object, verb-adjunct, verb-infinitive, verb-gerund, verb-that-clause, verb-predicate complement, and combinations of them (as we can see in Hornby 1945). Assuming that, like we found in this study for VO, all these verb-based patterns serve many different CFs, according to the sub-function theory each should have some communicative sub-function such as reference that can apply to many different communicative contexts. There is however a grave problem with the theoretical foundations of this possibility. We know from Searle's (1969) seminal work on speech acts that there are only two sub-functions of speech acts, which Searle calls prepositional acts: reference and predication. As far as philosophy of language is concerned, there are no other sub-functions that may be taken up by surface strings that we call phrases, and in fact it is difficult to think of any others that will hold water. It is reasonable that NPs (or DPs in present theories) are often used for reference, but it is less plausible that we can attach some meaningful function to such a unit as verb-object combinations. Until researchers in the Radical Construction Grammar tradition come up with a robust new Speech Act

Theory replacing Searle's in which there are many well-argued sub-functions, it seems that this idea will not be tenable.

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References

Akhtar, Nameera & Katherine H. Herold. 2009. Pragmatic development. In Marshall Haith & Janette B. Benson (Eds.), *Encyclopedia of Infant and Early Childhood Development,* Vol. *2* (pp. 572–581). San Diego, CA: Academic Press.

Ambridge, Ben, Amy Bidgood, Katherine E. Twomey, Julian M. Pine, Caroline F. Rowland & Daniel Freudenthal. 2015. Preemption versus entrenchment: Towards a construction-general solution to the problem of the retreat from verb argument structure overgeneralization. *PLoS ONE, 10* (4), e0123723.

Baraba'si, Albert–László & Réka Albert. 1999. Emergence of scaling in random networks. *Science, 286*(5439)**,** 509-512.

Bybee, Joan L. & Paul J. Hopper. (Eds.). 2001. *Frequency and the Emergence of Linguistic Structure*. Amsterdam: John Benjamins.

Chomsky, Noam. 1988. *Language and Problems of Knowledge: The Managua Lectures*. Cambridge, MA: The MIT Press.

Clark, Eve V. & Herbert H. Clark. 1979. When nouns surface as verbs. *Language, 55*(4), 767–811.

Cong, Jin & Haitao Liu. 2014. Approaching human language with complex networks. *Physics of Life Reviews, 11,* 598–618

Croft, William A. 2005. Logical and typological arguments for radical construction grammar. In Jan–Ola Östman & Mirjam Fried (Eds.), *Construction Grammars: Cognitive Grounding and Theoretical Extensions* (pp. 273–314). Amsterdam: John Benjamins.

Ferrer–i–Cancho, Ramon, Ricard V. Solé & Reinhard Kohler. 2003. Universality in syntactic dependency networks. *Santa Fe Institute Working Paper #03–06–042*.

Fillmore, Charles J. 1988. The mechanisms of "Construction Grammar". *Proceedings of the Fourteenth Annual Meeting of the Berkeley Linguistics Society* (pp. 35–55).

Givon, Talmy. 1997. Grammatical relations: An introduction. In Talmy Givon (Ed.), *Grammatical Relations: A Functionalist Perspective* (pp. 1–84). Amsterdam: John Benjamins.

Glinert, Lewis. 1989. *The Grammar of Modern Hebrew*. Cambridge: Cambridge University Press.

Goffman, Erving. 1981. *Forms of Talk*. Philadelphia: University of Pennsylvania Press.

Goldberg, Adele E. 1995. *Construction Grammar*. Chicago: University of Chicago Press.

Goldberg, Adele E. 2003. Constructions: A new theoretical approach to language. *Trends in Cognitive Sciences, 7* (5), 219–224.

Goldberg, Adele E. 2005. Argument realization: The role of constructions, lexical semantics and discourse factors. In Jan–Ola Östman & Mirjam Fried (Eds.), *Construction Grammars: Cognitive Grounding and Theoretical Extensions*. (pp. 17–43). Amsterdam: John Benjamins.

Hornby, Albert Sydney. 1945. *A Guide to Patterns and Usage in English*. London: Oxford University Press.

Hudson, Richard. 1984. *Word Grammar*. Oxford: Basil Blackwell.

Langacker, Ronald W. 1987. *Foundations of Cognitive Grammar, Vol. 1: Theoretical Prerequisites*. Stanford, CA: Stanford University Press.

Lieven, Elena. 2009. Developing constructions. *Cognitive Linguistics, 20* (1), 191–199.

Liu, Haitao. 2009. Statistical properties of Chinese semantic networks. *Chinese Science Bulletin, 54* (16), 2781–2785.

Liu, Haitao & Jin Cong. 2014. Empirical characterization of modern Chinese as a multi-level system from the complex network approach. *Journal of Chinese Linguistics, 42* (1), 1–38.

Maslov, Sergei, Kim Sneppen & Uri Alon. 2003. Correlation profiles and motifs in complex networks. In Stefan Bornholdt & Hans Georg Schuster (Eds.) *Handbook of Graphs and Networks: From the Genome to the Internet* (pp. 168–198). Berlin: Wiley-VCH.

Maslov, Sergei, Kim Sneppen & Alexei Zaliznyak. 2004. Detection of topological patterns in complex networks: Correlation profile of the Internet. *Physica A: Statistical Mechanics and its Applications, 333,* 529–540.

Newman, Mark E. J. 2002. Assortative mixing in networks. *Physical Review Letters, 89*, 208701–208704.

Ninio, Anat. 2006. *Language and the Learning Curve: A New Theory of Syntactic Development*. Oxford: Oxford University Press.

Ninio, Anat & Polly Wheeler. 1987. A manual for classifying verbal communicative acts in mother–infant interaction-revised. *Transcript Analysis, 3*(1), 1–83.

Ornan, Uzi. 1979. *Hamishpat Hapashut [The Simple Sentence].* Jerusalem: Academon.

Pinker, Stephen. 1984. *Language Learnability and Language Development*. Cambridge, MA: Harvard University Press.

Sacks, Harvey, Emanuel A. Schegloff & Gail Jefferson. 1974. A simplest systematics for the organization of turn-taking for conversation. *Language, 50*(4), 696–735.

Saussure, Ferdinand de. 1922/1983. *Course in General Linguistics.* (R. Harris, Trans.). London: Duckworth.

Searle, John R. 1969. *Speech Acts: An Essay in the Philosophy of Language*. Cambridge: Cambridge University Press.

Sethuraman, Nitya & Judith C. Goodman. 2004. Children's mastery of the transitive construction. In Eve V. Clark (Ed.), *Online Proceedings of the 32nd Session of the Stanford Child Language Research Forum* (pp. 60–67). Stanford, CA : CSLI Publications.

Steyvers, Mark & Joshua B. Tenenbaum. 2005. The large-scale structure of semantic networks: Statistical analyses and a model of semantic growth. *Cognitive Science, 29*(1), 41–78.

Tesnière, Lucien. 1959. *Éléments de Syntaxe Structurale*. Paris: Klincksieck.

Tomasello, Michael. 2003. *Constructing a Language: A Usage-Based Theory of Language Acquisition*. Cambridge, MA: Harvard University Press.

Tomasello, Michael. 2006. Construction grammar for kids. *Constructions*, Special Volume 1, 11/2006.

Vitevitch, Michael S. 2005. *Phonological Neighbors in A Small World: What Can Graph Theory Tell us about Word Learning?* Paper presented to the Complex Systems and Networks Group at Indiana University.

Watts, Duncan J. & Steven H. Strogatz. 1998. Collective dynamics of 'small–world' networks. *Nature, 393*, 440–442.

Wittgenstein, Ludwig. 1953/1978. *Philosophical Investigations* (Gertrude E. M. Anscombe, Trans.). Oxford: Blackwell.