

A LANGUAGE EMERGENCE MODEL PREDICTS WORD ORDER BIAS

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The majority of extant languages have one of three basic word orders: SVO, SOV or VSO. Various hypotheses have been put forward to explain aspects of this bias, including the existence of a universal grammar, learnability imposed by non-linguistic-specific cognitive constraints, and the descent of the extant languages from a common ancestral proto-language. Here, we adopt a multi-agent model for language emergence that simulates the coevolution of a lexicon and syntax from a holistic signaling system. The syntax evolves through a process of categorization; local syntactic rules are constructed that assign a relative order (e.g., S before V) to the elements of the two categories to which each rule applies. We demonstrate that local syntax encoding the relative position of S and O are the most stable, allowing the coexistence of the global word order pairs SOV/SVO and VOS/OVS. The structure of the semantic space that the language encodes further constrains the global syntax that is stable.

1. Introduction

Declarative sentences involving a verb (V), a subject (S) and an object (O) have one of six logically possible word orders. Greenberg (1963) observed that only three of these basic word orders are common among the world's extant languages: SVO, SOV and VSO. A number of hypotheses have been put forward to explain this bias. Some researchers (e.g., Briscoe, 2000) have argued that the acquisition of word order is influenced by the parameters of a built-in universal grammar. Others emphasize the role of non-linguistic-specific cognitive constraints to learning word order (e.g., Lupyán & Christiansen, 2002). Recently, Gell-Mann and Ruhlen (2005) have enumerated the numbers of languages belonging to each of the world's extant language families (as classified by Ruhlen, 1991) that have the orders SVO, SOV and VSO. From these data, they have concluded that "if there was a language from which all modern languages derive it had the word order SOV". The general trend that they have observed in basic word order is for the gradual fronting of the verb from sentence final position to sentence initial position while maintaining the relative position of the subject before the object.

Here we investigate bias in basic word order by studying the behavior of a new simulation model for language emergence proposed by Gong et al. (2006)

in this volume. In this model, word order is encoded locally by assigning a relative order (e.g., S before V) to lexical items belonging to pairs of categories that emerge gradually during the simulation. Our aim is to examine the degree to which bias in basic word order can be explained by self-organization resulting from competition among such local syntax rules and the structure of the semantic space that can be cognized by language users.

2. The Emergence of Word Order

Gong et al. (2004, 2005) have developed a model for the phylogenetic emergence of language to show that a population of interacting language-capable individuals can acquire a common lexicon and word order as a result of a simple local learning algorithm that is based on the detection of recurrent patterns. However, the model suffers from the shortcoming that the semantic structures that the individuals can manipulate map directly to corresponding syntactic structures. The authors have now extended the model (Gong et al., 2006, in this volume) to model the emergence of the syntax itself. Speakers acquire lexical items by detecting recurrent patterns in both the meaning and the form of perceived utterances, just as in the previous model. However, in this new framework, the syntax evolves through a process of categorization: Lexical items are assigned to the same category when an individual observes that those items have the same relative order with respect to some other item. For example, an individual who observes that two predicates “eat” and “drink” both come before—but not necessarily immediately before—the agent “cat” may create a category containing both predicates. The knowledge that these predicates precede the agent “cat” (or a category containing it) is then stored as a *local syntax rule*. As the categorization process continues, so increasingly many lexical rules become assigned to categories, so allowing an increasing proportion of the language to become compositional under the regulation of local syntax. Eventually, the emergent syntax may evolve to the point that all lexical items in an utterance are consistent with a particular *global syntax* (by which we mean the syntax of an entire utterance, e.g., SOV) that results from the combination of several local syntax rules. Thus global syntax is viewed as merely an emergent property of the local syntax rules that emerge. For further details of the model, refer to the paper by Gong et al. in this volume.

Our aim here is to investigate the bias in word order that is predicted to emerge in a language whose syntax is encoded locally. We begin by describing the relative persistence of the word orders that can emerge. The semantic space of the model comprises a set of integrated meanings of two types: Type-I

integrated meanings, which consist of a predicate that takes one argument, its agent, and Type-II integrated meanings, which consist of a predicate that takes two arguments, an agent and a patient.

For utterances that encode Type-I integrated meanings, there are only two possible local word orders, *SV* and *VS*. If sufficiently many individuals acquire a preference for one particular order, then that order will tend to diffuse across the entire population, resulting in the emergence of a shared word order for Type-I integrated meanings. Thus a one-to-one mapping between the semantic structure and syntactic structure will have emerged.

For utterances that encode Type-II integrated meanings, however, the situation is more complex. There are three pairs of competing local word orders: *SV* and *VS* (as for Type-I utterances), *SO* and *OS*, and *VO* and *OV*. The global syntax of Type-II utterances emerges in several steps as each local syntax rule is formed. Let us assume, for example, that the *SV/VS* competition completes first. What resultant bias in the global syntax for Type-II utterances should be expected to emerge? Suppose, for the sake of argument, that it is *SV* that wins the competition with *VS*. This local syntax is invoked only for utterances having surface forms that are consistent with one of three global word orders: *OSV*, *SOV* and *SVO*. Two of these word orders are consistent with *SO*; only one is consistent with *OS*. Therefore, if individuals perceive utterances having each of these global orders with equal probability, *SO* will be preferred to *OS*. If *SO* is indeed the second local syntax rule to emerge, the global syntax will tend to fluctuate between *SOV* and *SVO*, both of which are consistent with the local syntax *SV* and *SO*. Similarly, emergence of *OV* will lead to fluctuation of the global syntax between *OSV* and *SOV*. We refer to such syntax as *imprecise*.

If, however, *OS* emerges second, the two local syntax rules, *SV* and *OS*, give rise to a single emergent global syntax: *OSV*. We call such a syntax *precise*. One might expect this syntax to persist due to the subsequent competition between *VO* and *OV* leading to *VO* being reduced in strength for being inconsistent with the global word order *OSV*, thereby reinforcing the global order *OSV*. However, *SOV* and *SVO* are more likely to persist in practice because of the greater expected frequency of utterances having surface form consistent with *SO*. Other combinations of local syntax rules influence global syntax similarly.

To summarize, combinations of local syntax rules that generate an imprecise syntax tend to persist, while those that generate a precise syntax tend not to persist.

3. The Observed Bias in Global Word Order

The previous section explains the bias in the persistence of global word order that we predict to result from different combinations of emergence of local syntax. So far, we have neglected the impact of the structure of the semantic space—for example, Type-I sentences and Type-II sentences might not be produced with equal frequency. In order to explore the validity of the predictions above, we have run the model for various sets of parameter values that control the structure of the semantic space and the initial language of the population.

The structure of the semantic space depends on the relative proportions of agents, patients and predicates that make up the integrated meanings that can be expressed. In the experiments that follow we generate the semantic space of integrated meanings from 4 agents/patients, 4 predicates taking one argument and 4 predicates taking two arguments. As a result, the semantic space consists of 16 Type-I integrated meanings and 48 Type-II integrated meanings. In each experiment, a population of 10 individuals is initialized with a shared compositional language comprising a complete set of lexical items and two local syntax rules by which the lexicon is regulated. In some experiments, the initial local syntax is precise, generating a single global word order. In other experiments, the initial local syntax is imprecise, generating two, competing global word orders. Each simulation is run for 5,000 communications. Each experiment is repeated 20 times.

For our first experiment, we set a three-fold token bias in favor of Type-I sentences. This models a situation in which individuals express the two sentence types with equal probability. In our first experiment, each individual in the population is initialized with a common compositional language having the precise local syntax *SV+VO*. The evolution of the syntax for one run is summarized in Figure 1: the top row of 3 panels shows the evolution of the local syntax; the second and third rows show the resultant evolution of the global syntax. Panels show the average proportions of integrated meanings for which individuals invoke the corresponding syntax in order to comprehend utterances.

The initial syntax *SV+VO* quickly evolves, *VO* falling in strength to be replaced by *SO*. As a result, the global syntax *SOV* starts to compete with the initial global syntax *SVO*. This syntax remains stable for about 1,200 communications at which time the competition between *VO* and *OV* shifts in favor of *OV*. This shift triggers *SO* to flip to *OS*, which in turn triggers *SV* to shift to *VS*. While this reorganization is ongoing, the global syntax *OSV* briefly invades the language. The effect of this reorganization of the syntax, however,

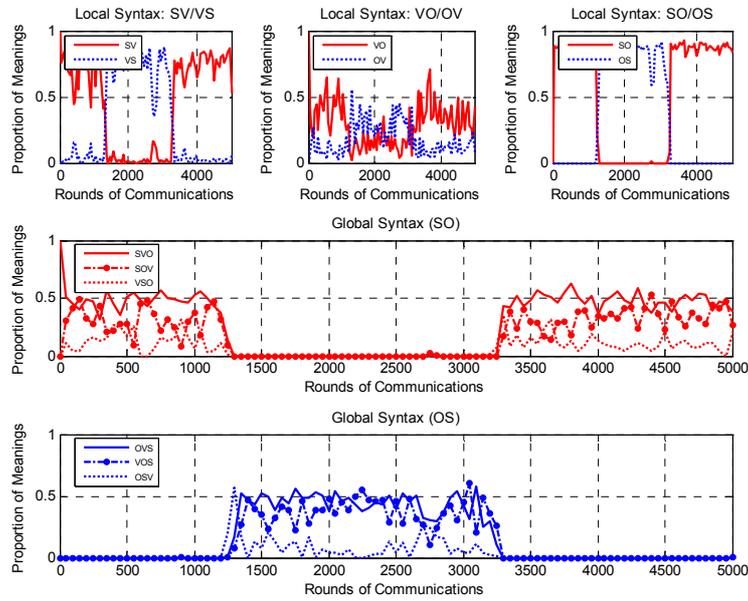


Figure 1. The evolution of syntax for an initial SV+VO compositional language.

is to shift the global syntax to OVS/VOS. Thus, two abrupt, synchronized transitions in the local syntax have brought about an inversion of the global syntax. For the next $\sim 1,800$ communications, the local syntax OS+VS remains stable, producing the two global word orders OVS and VOS. The system then undergoes another reorganization back to the original state of SO+SV.

The behavior just described is typical, not only of runs in which the initial syntax is SV+VO, but also for all other combinations of local syntax that we have examined: SV+SO, SV+OV, SO+OV, VS+SO, VS+OS. We conclude that, for a semantic space with a three-fold bias toward Type-I sentences, the system has only 4 qualitative states, as shown in Table 1.

In almost all runs, SO/OS is the most stable pair of local syntax rules. To understand why this should be the case, consider a syntax in which the relative order of S and O is not specified, e.g., SV+OV \rightarrow SOV/OSV. When an individual hears an utterance encoded using this syntax, he is unable to use this syntax to distinguish the agent of the sentence from the patient. This combination of local syntax rules is therefore selected against, existing only as a transient state.

Table 1. Stable states of the local syntax and the resultant global syntax (Type-I : Type-II bias 3:1). The most frequently occurring syntaxes are also the most stable. The syntaxes marked as TRANSIENT occur only as transient states when the language reorganizes from one stable syntax to another. Other transient states occur only rarely, e.g. SO+VO→SVO/VSO. Precise grammars exist only as transient states. The stable syntaxes are all imprecise, as predicted in Section 2.

Local Syntax	Global Syntax	Stability
SO + SV	SOV and SVO	STABLE
OS + VS	VOS and OVS	STABLE
SO + VS	VSO	TRANSIENT
OS + SV	OSV	TRANSIENT

Some combinations of SV/VS and OV/VO, however, are not subject to this form of instability, e.g., the syntax SV+VO. This syntax is precise, specifying the unique global word order SVO, hence no such ambiguity arises. Nevertheless, because it is a precise syntax, it too exists only as a transient state. Precise syntaxes are quickly replaced because a third local syntax rule—SO in this case—can invade the language with no immediate reduction in communicative success. One of the two preexisting rules soon becomes redundant, causing the syntax to become imprecise (e.g., SV+SO). Change back to the precise syntax is then difficult because the imprecise syntax is now consistent with two global word orders, only one of which can be supported by the previous precise syntax. This same reasoning also explains the transient nature of the precise syntaxes SO+VS and OS+SV.

One further phenomenon of the evolution of syntax requires explanation. Why are the imprecise syntaxes SO+VO and OS+OV not also stable? To understand this we must consider the relative frequency of Type-I and Type-II sentences. Because of the three-fold bias in favor of Type-I sentences, which involve only S and V, the pair of local syntax rules SV and VS are reinforced frequently. They therefore stabilize before OV and VO, preventing the SO+VO and OS+OV syntaxes from occurring.

In a separate experiment, we set the Type-I:Type-II bias to 1:1. Individuals therefore make more frequent use (×3) of Type-II sentences than of Type-I sentences, reflecting a preference for more complex structures integrated meanings. This leads to the Type-II-specific local syntax rules being reinforced more quickly. As a result, there is no bias away from acquiring the OV and VO rules. The dominance of SO/OS, however, is maintained. Table 2 summarizes the stability of the syntax for this case.

Table 2. Stable states of the local syntax and the resultant global syntax (Type-I : Type-II bias 1:1).

Local Syntax	Global Syntax	Stability
SO + SV	SOV and SVO	STABLE
SO + VO	VSO and SVO	STABLE
OS + VS	VOS and OVS	STABLE
OS + OV	OSV and OVS	STABLE
SO + VS	VSO	TRANSIENT
SO + OV	SOV	TRANSIENT
OS + SV	OSV	TRANSIENT
OS + VO	VOS	TRANSIENT

In a final experiment, we set the Type-I : Type-II bias to 9:1 so that Type-I utterances were three time more frequent than Type-II sentences, reflecting a preference for simply structured integrated meanings. This semantic space generates the most stable syntaxes of all the cases that we have examined. In runs in which the initial compositional language is **SV+SO**, for example, the initial syntax is never replaced. The large preponderance of Type-I sentences means that the relative order of **S** and **V** are reinforced very often, preventing any new syntax from invading the language. We expect such stability to extend to other initial compositional languages.

4. Conclusion

The simulation results presented here demonstrate that bias in the word order of simple utterances is constrained primarily by the need to distinguish the agent and the patient, although the structure of the semantic space that the language encodes also has some effect. For all initial compositional languages that we have studied, the competition between **SO** and **OS** drives the evolution of global syntax. When **SO** is dominant, the local syntax **SV** tends to emerge also, generating the global syntaxes **SOV** and **SVO**. All other combinations of local syntax are transient. When **OS** is dominant, the prevailing global word orders are reversed: **VOS** and **OVS** tend to co-exist.

Empirical observations of the relative frequencies of each word order among the extant languages indicate that **SOV** and **SVO** are by far the most common word orders, with **VSO** being the next most frequent (Gell-Mann & Ruhlen, 2005). Our results are largely consistent with this empirical finding,

although our model predicts that OS+VS, generating the global syntax VOS and OVS is also common.

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