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# The emergence of compositional structures in perceptually grounded language games

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## Abstract

This paper describes a new model on the evolution and induction of compositional structures in the language of a population of (simulated) robotic agents. The model is based on recent work in language evolution modelling, including the iterated learning model, the language game model and the Talking Heads experiment. It further adopts techniques recently developed in the field of grammar induction. The paper reports on a number of different experiments done with this new model and shows certain conditions under which compositional structures can emerge. The paper confirms previous findings that a transmission bottleneck serves as a pressure mechanism for the emergence of compositionality, and that a communication strategy for guessing the references of utterances aids in the development of qualitatively ‘good’ languages. In addition, the results show that the emerging languages reflect the structure of the world to a large extent and that the development of a semantics, together with a competitive selection mechanism, produces a faster emergence of compositionality than a predefined semantics without such a selection mechanism.

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## 1. Introduction

One recent trend in models of language learning is the emergence of an increasing number of models simulating certain aspects of the origins and evolution of language, see [9,11,25,45] for overviews. This paper presents a new model to study the emergence and dynamics of compositional structures in languages whose semantics are connected with a simulated world. Although this world is far from realistic, it can be—and has been—implemented physically using real robots [49].

The ability to form compositional structures—as part of syntax—is one of the key aspects of human language. Here is a definition of compositionality that was taken from a web-site of a recent series of conferences on compositionality:<sup>2</sup> “Compositionality is a key feature of structured representational systems, be they linguistic, mental or neuronal. A system of representations is compositional just in case the semantic values of complex representations are determined by the semantic values of their parts.” For instance, the sentence “give me the book” can be described semantically as `give(me, thebook)`, where the word “give” maps onto the action `give`, “me” onto the person `me` and “the book” onto the object `thebook`. In contrast, *holistic* expressions have no structural relations between parts of the expressions and parts of their meanings. In “kicked the bucket” when used to mean `died`, for instance, no part of the expression has a relation to any part of the meaning `died` (apart from the aspect of tense).<sup>3</sup>

One of the frequently asked questions in studies on language origins and evolution is: how could compositional structures in human languages have emerged? One line of research assumes that compositional structures emerged from exploiting (e.g. random) regularities found in protolanguages based on holophrases [67], a line of research that has been adopted by many computational modellers, most notably [6,20,23]. In these studies, it was shown that compositional structures in language can emerge when the learning examples do not cover the entire language (i.e., there was a *bottleneck* on the transmission of language [20]), provided the learners have a predefined mechanism for acquiring compositional structures. Other researchers have assumed that the ability to use syntax has evolved as a biological adaptation [34], as modelled in, e.g., [8]. Yet other modellers have assumed that compositional structures can emerge based on competition between exemplars [2] and self-organisation in a production system [46]. Note that in all computer models developed so far, learning mechanisms have been implemented that can acquire compositional structures. Hence, all studies use the assumption that a specialised learning mechanism has evolved prior to the ‘emergence’ of compositional languages, and therefore investigate the

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<sup>2</sup> See <http://www.phil-fak.uni-duesseldorf.de/thphil/compositionality/> and <http://www.cognition.ens.fr/nac2004/>.

<sup>3</sup> Note that these examples are extreme and “easy” examples of compositionality. There are many other interesting aspects of compositionality that are not covered by these examples. The given examples, however, suffice for the purpose of this paper.

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