How ecological regularities can shape linguistic structures

Paul Vogt, Tilburg University, The Netherlands, p.a.vogt@uvt.nl

A hot topic in language evolution and computation is modelling the emergence of compositional structures in language, see, e.g., (Batali, 1998; Kirby, 2001). However, these models typically take a compositional structure of the meaning space for granted. Moreover, these models assume a predefined meaning space and all the agents in these models have to do is develop a syntactic language. I agree that this is important research from which we learn a lot, but these studies are bound to overlook crucial aspects of symbol grounding, at least to some extent.

One trap that may appear is that one overlooks the possiblity that agents can exploit the interaction with the environment. In this paper I will illustrate, using computational modelling, how agents can exploit regularities of their ecological niche to shape the compositional structures they evolve culturally in language. In this model, agents develop a compositional structure based on a number of perceptual features (3 features to represent colour and 1 to represent shape). The implicit goal is to develop a compositional language in which sentences are expressed by two components. Initially, the agents have no clue which features belong to colour and which to shape. Naturally, we hope to find that the emergent components distinguish between colours and shapes.

The model combines the principles behind the Talking Heads experiment (Steels et al., 2002) with the iterated learning model as was implemented in (Kirby, 2001), and is described in detail elsewhere (Vogt, 2003). In the iterated learning model, language evolves by iterating a cycle in which learners learn language by observing the linguistic behaviour of adults, until the adults 'die', learners become adults and new learners enter the population. When learners enter the population, they have no categories (meanings), words or grammar; these develop during their 'lifetime'.

The environment of the agents contains a given number of distinctive shapes, which can have a fixed number of different colours. Initially, perceptual features are categorised holistically, i.e. by forming categories as regions in a conceptual space that covers all quality dimensions (perceptual feature dimensions). By finding regularities in the categories that the agents use in different situations, the agents are able to group those quality dimensions that have similar values. For instance, suppose a learner uses category (1,1,1,0) for an object that the adult called "wateve" and category (1,1,1,1) for an object the adult calls "foreve". Then the learner groups the first 3 dimensions of the categories and seperate these from the final one to form conceptual spaces (linguistic categories) of lower dimensions. Likewise, it can decompose the, initially, holistic phrases "wateve" and "foreve" into constituents such as "wat", "for" and "eve". Furthermore, the learner can learn a rule to combine the constituents, and that "wat" means (?,?,?,1), "for" means (?,?,?,0) and "eve" means (1,1,1,?), where the ?s can have any value. This mechanism may seem trivial, but due to the incremental development of concepts, which differ in trajectory from agent to agent, the induction is typically not so straightforward as illustrated by the example. Note that the mechanism illustrated at the syntactic level was implemented in (Kirby, 2001) and which is thought to occur with human language learners as well (Tomasello, 2000). Combining the two mechanisms, the model exploits a co-development of semantic and syntactic structres.

Simulations are presented that show how a compositional language can emerge from scratch. Moreover, the languages that emerge typically reflect the regularities found in the perceptual features agents detect when seeing their environment, and contains linguistic structures concerning colours and shapes both at the syntactic and semantic level. Summarising, the simulations show that a compositional language can evolve through a combination of cultural evolution (at the syntactic level), simple induction mechanisms and the interaction of agents with their environment.

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