SYNONYMS AND HOMONYMS IN SIGNALING GAME – WHICH ARE STABLE AND WHEN?

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Evolution and structure of language is often analysed using computational modelling (Cangelosi & Parisi, 2002; Nolfi & Mirolli, 2010; D'Ulizia, Ferri, & Grifoni, 2020). A particularly appealing research paradigm is inspired by the idea that language might have spontaneously appeared in a population of communicating individuals, possibly with some adaptive features (Pinker & Bloom, 1990). This standpoint prompted numerous analysis of multi-agent models, which mimic such communication and try to infer the properties of the emerging language and its possible further evolution (Steels, 2012; Gong, Shuai, & Zhang, 2014; Kirby, Griffiths, & Smith, 2014).

In certain models of this kind, language emergence and evolution is studied using the signaling game (Lewis, 2002), where communicating agents must decide which signal to send or how to interpret the signal they have received. To cope with this, agents very often use some form of the reinforcement learning (Skyrms, 2010; Lenaerts, Jansen, Tuyls, & De Vylder, 2005; Barrett, 2006; Franke, 2016; Mühlenbernd & Franke, 2012; Lipowska & Lipowski, 2018).

By taking signals as words, we can regard the form-meaning mapping that emerges during the signaling game as language. The mapping can be a one-to-one correspondence (in a signaling game terminology, it is a signaling system), but there are also other possibilities, namely, homonyms or synonyms can emerge. Neglecting some linguistic nuances (Ravin & Leacock, 2000), we can posit that in the case of homonymy, one word carries different meanings while synonymy means that a single concept is expressed by different words.

It seems quite plausible that synonyms or homonyms change in time. For example, the frequency of their usage may change and gradually one form will be preferred over the other, and the latter eventually can even disappear. Although linguistic data are difficult to interpret, there are some indications that in natural languages synonyms are quite rare in contrast to homonyms, which appear to be more common (Hurford, 2003; Clark, 1990). Some linguists even insist that true synonyms do not exist or at best are very rare compared to homonyms (Lyons, 1981; Goldberg, 1995). There are some arguments that the difference in

the frequency of synonyms and homonyms may be due to evolutionary pressures favouring speakers rather than hearers (Hurford, 2003), or to language acquisition in childhood (Markman, 1989).

Let us notice that synonyms actually compete in a quite different way from homonyms, which can be demonstrated already within the framework of the signaling game. While synonymous words compete for being selected by a speaker, for a homonymous word, it is the hearer's role to assign an appropriate interpretation. It is thus possible that such a difference can affect an overall dynamics of synonyms and homonyms and eventually result in different degrees of their prevalence.

We approached the problem of evolution and stability of synonyms and homonyms using computational modelling. Within the framework of the signaling game, we show that the reinforcement learning should operate in the so-called super-linear regime with probabilities of selections increasing faster than linearly with the accumulated weights. The linear regime would, instead, lead to languages with very stable synonyms and relatively fast decaying homonyms, which is probably at odds with some linguistic observations (Hurford, 2003). Our work indicates that the prevalence and evolution of synonoyms and homonyms in natural languages may give us some valuable clues as to the nature of the mechanisms that drive linguistic processes. More details concerning our model and the results obtained can be found in (Lipowska & Lipowski, 2022).

Perhaps an interesting question is why nonlinear rather than the simplest (maybe naively expected) linear feedback drives linguistic processes. Related studies, under mathematically similar setup of the so-called urn models, in certain marketing or economic contexts showed that the value of the system grows faster than linearly with the number of users. Such a behaviour seems to characterize competition between, e.g., video formats, operating systems, and even types of keyboards. In the literature, it is referred as Metcalfe's Law (Shapiro & Varian, 1998; Arthur, 1994). In the signaling game and in linguistic context, it would mean that a benefit of using a certain word (and thus a probability of its future selection) increases faster than linearly with the number of successful communications. Considering the complexities of language evolution, with its various social, biological, and cognitive aspects, it seems quite likely.

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