When used in context, homonyms can persist in signaling game

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Signaling game is a paradigmatic approach to studying the emergence of language as a result of communicative interactions (Lewis 1969). Analysis of the standard signaling game shows that, typically, communicating agents achieve a signaling system, i.e., a one-to-one correspondence between forms and meanings, without homonyms or synonyms (Lipowska, Lipowski 2022a,b; Mühlenbernd 2021; Mühlenbernd *et al.* 2022). In contrast, there are many ambiguous words in natural language (Ravin, Leacock 2000; Santana 2014).

We examined a model of multi-agent signaling game with reinforcement learning, which takes contextuality into account, to check its influence on the evolution of homonyms. Here, context denotes additional information sent to the receiver, which can help to recognise the signal. Such a context significantly affects the evolution of the model. Simulations demonstrate that contextuality can stabilise homonyms.

Agents in our model select a communicated word or its interpretation with a probability expressed as a power law of its weight that accumulates past successful communication attempts (probability $\sim$ weight$^{\alpha}$). The behaviour of the model to some extent hinges on whether this probability depends on the weight linearly ($\alpha = 1$) or superlinearly ($\alpha > 1$). For uniform initial configurations, in the linear regime, contextuality can hinder the formation of a signaling system, while in the superlinear regime, it can even speed up the process. We have also performed simulations with homonymous initial configurations to examine the stability of such structures. Numerical results show that in the absence of contextuality, homonyms disappear, while in its presence, homonyms persist.

We can approximate our signaling game model with an urn model and obtain analytically some insight into the behaviour of homonyms. Analysis shows that in the case of contextuality, only symmetric homonyms can exist in the linear regime, while in the superlinear regime—nonsymmetric homonyms (here, symmetric are those whose meanings are recognised with equal probability). In our opinion, symmetric and nonsymmetric homonyms resemble balanced and polarised homonyms (in linguistics, they are homonyms with meanings used with the same or different frequency, respectively (Armstrong *et al*. 2012)). The problem is quite subtle, however, and possibly the comparison is not entirely accurate. Nevertheless, we find it interesting to demonstrate that such two types of homonyms can emerge within a signaling game.

Contextuality is certainly present in our communication, and modelling language formation processes should take this aspect into account. The fact that we effectively communicate in a language containing balanced and polarised homonyms suggests that the signaling game with $\alpha > 1$ provides a better (than $\alpha = 1$) description of human communication.

References

Armstrong, Blair C., Natasha Tokowicz, and David C. Plaut (2012) eDom: Norming software and relative meaning frequencies for 544 English homonyms. *Behavior Research Methods* 44, 1015-1027.

Lewis, David K. (1969) *Convention: A Philosophical Study*. Cambridge, MA: Harvard University Press.

Lipowska, Dorota, and Adam Lipowski (2022a) Stability and evolution of synonyms and homonyms in signaling game. *Entropy* 24, 194.

Lipowska, Dorota, and Adam Lipowski (2022b). Emergence and evolution of language in multi-agent systems. *Lingua* 272, 103331.

Mühlenbernd, Roland (2021) Evolutionary stability of ambiguity in context signaling games. *Synthese* 198, 11725-11753.

Mühlenbernd, Roland, Sławomir Wacewicz, and Przemysław Żywiczyński (2022) The Evolution of Ambiguity in Sender–Receiver Signaling Games. *Games* 13, 20.

Ravin, Yael, and Claudia Leacock (eds.) (2000) *Polysemy: Theoretical and Computational Approaches*. Oxford, UK: Oxford University Press.

Santana, Carlos (2014) Ambiguity in cooperative signaling. *Philosophy of Science* 81, 398-422.

Tang, Liping (2021) Ambiguity and context learning in signalling games. *Journal of Logic and Computation* 31, 1979-2003.