

## **CULTURAL EVOLUTION AND COMMUNICATION YIELD STRUCTURED LANGUAGES IN AN OPEN-ENDED WORLD**

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Language maps signals onto meanings through two types of structure. Firstly, the space of meanings is structured into shared categories. Secondly, the signals employed by a language are structured such that the meaning of the whole is a function of the meanings of its parts and the way in which those parts are combined. Previous work has demonstrated that structured categories (e.g., Xu, Dowman, & Griffiths, 2013) or structured signals (e.g., Kirby, Cornish, & Smith, 2008) can arise through iterated learning. However, the simultaneous emergence of these two types of structure has not been shown experimentally, leading to concerns that one type of emergent structure is simply an artefact of the other.

To explore this issue, we conducted a series of iterated learning experiments using a vast, open-ended, continuous meaning space. The first participant in a transmission chain was trained on 48 randomly generated signals paired with 48 triangles generated by selecting three coordinates at random in a  $480 \times 480$ -pixel box, yielding a space of  $6 \times 10^{15}$  possible stimuli. In a test phase, the participant was asked to label 96 novel triangles, none of which had been seen during training. The output from this test phase became the input to the next generation.

In the first experiment, we ran four chains, each with ten generations. Over time, the space of triangles was categorized into an increasingly small number of discrete regions, which consecutive participants increasingly align on. These

emergent categories, labelled with holistic signals, typically discretized the space of triangles based on their shape and size, ignoring features such as location and orientation (cf., Landau, Smith, & Jones, 1988). There was a cumulative increase in structure, showing that category systems can arise through iterated learning.

Our second experiment used the same experimental design, except at each generation a pair of participants were trained on the language separately and then entered a communication phase in which they took turns to communicate about triangles to each other. One participant was presented with a triangle and was asked to label it for their partner; the communicative partner then had to select the correct target triangle from a selection of six. The output from this communication phase became the input to the next generation in the chain.

The languages in this experiment, where there is a natural pressure for expressivity (Kirby, Tamariz, Cornish, & Smith, 2015), contained more unique signals. Despite these higher levels of expressivity, there was also a cumulative increase in structure in the languages. Furthermore, we found evidence that two of the four chains contained sublexical structure in addition to the categorical structure we observed in the non-communicative experiment. This sublexical structure was driven by shape-based sound symbolism and had morphological features similar to those found in natural languages (such as cranberry morphs; Aronoff, 1976).

Whereas previous iterated learning experiments have been limited to two types of result — categorical structure in meanings or compositional structure in signals — these experiments demonstrate that an alternative is possible. When the space of meanings is open-ended, and lacks clear pre-existing boundaries, then more subtle morphological structure, lacking straightforward compositionality, may evolve as a solution to the joint pressures from learning and communication.

## References

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