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**SYSTEMS EMERGE: THE CULTURAL EVOLUTION OF  
INTERDEPENDENT SEQUENTIAL BEHAVIOURS IN THE LAB**

SIMON KIRBY

*Language Evolution and Computation Research Unit, School of Philosophy, Psychology  
& Language Sciences, University of Edinburgh, EH8 9AD, UK  
simon@ling.ed.ac.uk*

HANNAH CORNISH

*Psychology, University of Stirling, Stirling, FK9 4LA, UK  
h.cornish@gmail.com*

KENNY SMITH

*Language Evolution and Computation Research Unit, School of Philosophy, Psychology  
& Language Sciences, University of Edinburgh, EH8 9AD, UK  
kenny@ling.ed.ac.uk*

What is the most fundamental property of human language? A reasonable answer is *systematicity*. Language is remarkable among natural behaviours in operating as a system at all levels of description. In other species, distinct calls in a communicative repertoire are typically independent from each other except to the extent that they are produced by the same vocal apparatus (Fitch, 2010), but human language is characterised by a complex web of interdependencies between utterances. When we talk of a language's phonology, morphology, syntax, semantics, or more broadly *grammar*, we are describing the precise ways in which messages in that language fail to be independent. It is this unusual systematicity of language that is at the heart of its other unusual (and apparently adaptive) property: productivity. Independence of signals would render generalisation, and consequently the productive application of those generalisations, impossible.

Systematicity is an obvious target of explanation for the evolutionary linguist. A productive line of research over recent years has been to view systematicity as emerging from a process of cultural evolution through iterated learning (Kirby, 2001; Kirby, Cornish, & Smith, 2008; Verhoef, 2012). But, to what extent has this work really demonstrated the genuine emergence of *systems* of behaviour? In many cases, the task for participants in an iterated learning experiment involves meanings that are systematically related to each other *a priori*, and even when this is not the case, for example in experiments where there are no meanings (Verhoef,

2012), participants nevertheless see a whole set of signals and later are explicitly asked to recall that set.

In this paper, we present results from a study in which participants carry out a series of 60 instant-recall tasks one after another, with the tasks being presented as entirely independent. Specifically, participants see a sequence of illuminated red, blue, green and yellow lights, and are then asked to reproduce the observed sequence. Participants are organised into diffusion chains such that each participant's responses to the tasks form the sequences that the following participant is exposed to. Crucially, the first participant in each chain is exposed to 60 random (and therefore genuinely independent) sequences.

Our experimental design creates 60 lineages of sequences for each chain of participants we run. These lineages evolve as participants make errors in recalling the sequences, but these errors tend to decline over generations, indicating that cultural evolution somehow leads to adaptation of the sequences for easier recall. How does this happen? One possibility is that some sequences are simply easier to remember, universally. However, in a follow-up study, by exposing a new set of participants to different sets of sequences derived from mixtures of the sequence sets produced across chains, we show that the set of 60 sequences lose independence and start acting in consort with each other. Participants show lower error on immediate recall of sequences that evolved together on one of our chains as opposed to a set made up of sequences that evolved in different chains. Each sequence acts to boost the memorability of each other sequence in the set. In other words, despite the fact that the experiment is designed as a series of independent trials, a *system* has emerged.

We predict that, wherever a large enough set of independent behaviours is transmitted through a process of imitation in nature, we can expect to see systematic properties emerge. The genesis of grammar lies in culture.

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