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What are the social, economic and ecological conditions
for the evolution of complex communication systems?
Comment on “Rethinking foundations of language from
a multidisciplinary perspective” by T. Gong et al.

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How did human language evolve? This is a fascinating question and Gong, Shuai & Wu [1] are correct: an interdisciplinary approach which recognises that language is a mosaic of domain-general abilities is the most productive way forward. I would like to suggest that even more productivity would result from a broader question: What are the conditions under which complex communication systems are more likely to evolve? This recognises that many other species have developed bits and pieces of human linguistic capacities: birdsong has complex syntax [2], vervet monkeys have ‘semantics’ in their alarm calls [3], and bee dances are compositional [4, 5]. These provide vital clues, not just to the cognitive requirements for linguistic abilities, but crucially for the wider social, economic and ecological conditions that motivate their emergence.

The literature on the evolution of cognition for communication sometimes reads like a march of progress towards the inevitable pinnacle of human language: other animals have collected some bits, but haven’t caught up with us yet. However, there is no inevitable progression in evolution, only selective pressures that shape traits. Humans alone found themselves in the right conditions for all the bits to come together. The new key question focusses on answering what *motivated* each piece to emerge. While genetic and cognitive factors are obviously part of the story, it is becoming increasingly clear that our human ancestors found themselves in critical social, economic and

ecological situations.

This is perhaps best exemplified by the abilities of primates in captivity. Several species have the ability to learn and use symbolic communication systems through intensive training [6, 7, 8, 9, 10, 11]. However, their natural habitats do not provide the right selective pressures for these latent abilities to develop into habitual behaviours. In contrast, many primate species have found themselves in the right conditions to exhibit vocal or gestural turn-taking in the wild [12], a different key ingredient for human language [13]. The vast majority of work in language evolution has focussed on comparisons between cognitive capacities, but a comparison of ecologies should also provide some clues about the conditions for the evolution of complex communication.

Gong et al. rightly point out that theories from anthropology and archaeology have a role to play here. There is now a wealth of theories from anthropology and archaeology about the kinds of conditions which plausibly create a need for complex communication [14, 15, 16, 17, 18, 19], including predation [20], hunting [21], navigation [22, 23], and reproductive strategies [24, 25]. For example, the move from dense jungle out into open savannah could have changed the availability of resources and created pressures to change foraging strategies and group dynamics [26]. This could have made larger social networks more feasible, and created greater pressures for advanced social communication [27]. However, a complex infrastructure that facilitates trust and material support within a group may have been necessary before symbolic communication was viable [24]. These infrastructures themselves may have been shaped by specific ecological and economic conditions, such as the ability to harness the environment more effectively by crafting tools [28, 29] and controlling fire [30]. Gong et al. do discuss the role of the socio-cultural environment, but the references focus on cognition and acquisition in shaping language, not the socio-cultural factors that motivated its emergence.

Indeed, there are few attempts to pull all of these theories together and test them systematically against each other, perhaps because there is no easy way to survey hypotheses spread out over so many disciplines. Gong et al.'s call for interdisciplinary work is welcome, but it must be supported by concrete suggestions for how to proceed. One possible solution is to formalise hypotheses by representing them as causal graphs [31]. The Causal Hypotheses in Evolutionary Linguistics Database (CHIELD) is one fledgeling attempt to do this [32]. Each theory typically involves several nodes (measur-

able quantities) and causal connections between them. Nodes may appear in several theories, providing a way to spot connections. The aim is to formally code many theories of language evolution, in order to capture long chains of causality which connect social, economic and ecological conditions with the emergence of specific linguistic abilities. CHIELD also tracks the amount of empirical support that each connection has, helping to find weak links and conflicting hypotheses. This helps guide research by suggesting key issues to resolve. Importantly, by breaking theories down into individual causal steps, each step can be addressed separately using the most appropriate method.

As Gong et al. also suggest, computational models, simulations and experimental approaches have a crucial role in testing these causal connections. For example, several proposed scenarios for the evolution of symbolic signals involve early humans needing to collaborate to refer to or manipulate physical objects or build complex constructions [33, 34]. To test this, Irvine & Roberts [35] ran an experiment where human participants had to build a shelter together in a virtual world (Minecraft). Participants were prevented from using speech during the experiment, but they were given the resources and capacity to construct a simple symbolic communication system to help them in the task. However, because the task could be completed by using pointing and trial-and-error strategies, there was no motivation to invent a symbolic system, and so none evolved. Irvine & Roberts concluded that the need to collaborate for construction was not a strong enough selective pressure on its own to motivate the emergence of a symbolic system. Overcoming the ‘fitness trap’ of pointing would likely require a pressure to refer to things far away in time or space. Several theories suggest where these pressures might come from such as ritual [24] or the organisation of hunting or trade [36], and these scenarios can also be simulated. Comparing the likelihood of a linguistic feature emerging under different situations can provide evidence for or against various theories.

Gong et al. seem skeptical that experiments with humans can provide relevant evidence for theories of language origins (as opposed to subsequent cultural evolution). However, the value of experiments such as the one above is not necessarily as realistic recreations of the specific steps of human language emergence, but as tools for thinking about the principles behind more general theories. They can help us systematically describe and explore theories of how a particular linguistic ability evolved as a response to particular social, economic or ecological factors. Taking a leaf from the book of synthetic biology [37], if we think we know how language evolved, we should

be able to create minimally different artificial environments which lead to linguistic communication in one case but not the other.

In effect, experiments like one above are using human participants as cognitively sophisticated black boxes for controlling agents in an artificial simulation. As Gong et al. point out, human experiments and computational simulations have complementary strengths and weaknesses (see also [38]), and it may be possible to swap out the human black boxes for computational ones. Neural nets are one obvious choice [39] which give agents the capacity for complex behaviour, but still require specific ecological conditions to emerge. Through parallel processing, this would allow testing on much longer timescales and a much wider range of ecological conditions. It also means that the more general question extends to exploring the most fertile conditions for communication in artificial life and human-machine interaction [40, 41, 42].

In summary, the time is ripe for collecting theories of the ecological conditions for complex communication and using simulation methods to formalise and test them. This virtual experimental archaeology is an ambitious idea that will surely create debate and disagreement but, as Gong & Shuai [43] suggest, failures along the way may teach us as much as successes.

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