THE COMMON TASK FRAMEWORK: USING CAUSAL THEORIES FROM LINGUISTIC ANTHROPOLOGY TO EXPLORE THE EMERGENCE OF SYMBOLIC COMMUNICATION

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We present the Common Task Framework approach to testing causal theories about the evolution of language. There are now many theories about how symbolic communication emerged, but less work trying to compare, synthesise and test these theories. We suggest that the first step is to formalize the theories as causal graphs using tools from the field of causal inference. This helps recognize the critical causal links that differentiate theories. The second step is to use tools from experimental semiotics to specify a "common task": an experimental environment and a task for individuals to complete. The different theories suggest different design solutions for this common task, and the success of the individuals can be used as a measure of the relative success of each theory. In this paper, we provide an example from anthropological theories of the emergence of symbolic communication, including coding 11 theories as causal graphs using the CHIELD database. We hope the common task framework will be applicable to many aspects of language evolution.

1. Introduction

Human language is the most complex communication system on earth, with no other animal coming close to our linguistic abilities. How did this ability evolve, and why only in humans? While genetic and cognitive differences are obviously part of the story, perspectives from anthropology and archaeology are making it increasingly clear that our ancestors also benefitted from critical social, economic and ecological situations. Some species including apes, birds and even insects have advanced communicative abilities (Berwick et al., 2011; Arnold & Zuberbühler, 2006; von Frisch, 1967) or can acquire them through intense training (e.g. Premack, 1971). However, apparently their natural habitats do not provide the right selective pressures for these latent abilities to evolve further. Only for humans did the right factors come together to motivate the evolution of complex language. Therefore, we argue that there is a critical unanswered question: *What*

are the social, economic and ecological conditions for the evolution of complex communication systems? (Roberts, 2018). We suggest that theories from **anthropology and archaeology** can help us answer this question.

There are two main challenges. The first is identifying the most prominent theories. More importantly, how do they agree or conflict with each other? Are there specific predictions that can be tested in order to evaluate the relative plausibility of each theory? Addressing this will require a systematic review of the literature and a way of formally representing the causal structure of theories. We suggest that **causal inference** can help researchers to do this.

The second challenge is how to test these theories against each other empirically. Since we cannot observe language evolution directly, and naturalistic methods provide limited flexibility, support for theories must come from a robust combination of approaches (Irvine, Roberts & Kirby, 2013). We suggest that a **common task framework** is needed that combines control from experimental semiotics and ecological validity from anthropology. This should be flexible enough to simulate many scenarios while being consistent enough to make comparisons across theories.

In this paper we outline how causal inference and a common task framework can meet the two challenges above. We illustrate the approach with examples related to the emergence of symbolic signals. However, because many questions about the evolution of language involve complex causal connections from multiple sources of evidence, and where direct experimentation is impossible, we hope that the common task framework will be a useful more generally for the field of evolutionary linguistics.

2. Formalising theories from anthropology and archaeology

There is now a wealth of theories from anthropology and archaeology about the kinds of tasks that plausibly created a need for complex communication in human evolutionary history (see e.g. Dor et al., 2014; Power et al., 2016). These include predation (Dunbar, 2017), hunting (Knight & Lewis, 2017; Sterelny, 2012), navigation (Bednarik, 1997), tool use (Davidson & Noble, 1989), fire making (Twomey, 2013; Wiesser, 2014), and reproductive strategies (Knight et al., 1995). While theories abound, there are few attempts to synthesise them and systematically test them against each other. We argue that causal inference provides a powerful approach that can express, explore and evaluate theories. One tool for helping researchers do this is the Causal Hypotheses in Evolutionary Linguistics Database (CHIELD, Roberts et al., 2020, http://chield.excd.org). CHIELD is a database of hypotheses which have been hand-coded as causal

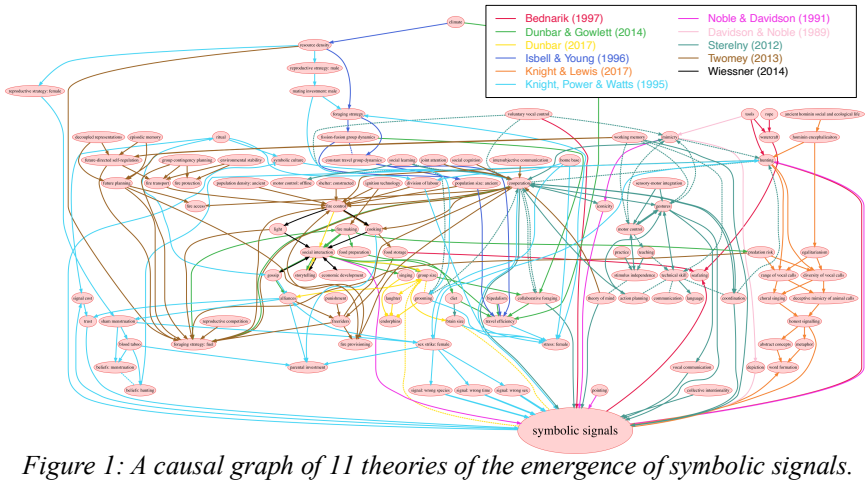

Figure 1: A causal graph of 11 theories of the emergence of symbolic signals.

graphs. This allows users to discover formal links between hypotheses, assess conflicting evidence and spot weak links that currently have little support.

Using CHIELD, we formalized 11 theories as causal graphs (Fig. 1, see supporting materials). There were two major findings from this exercise. The first is that the theories are deeply interconnected. 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 (Isbell & Young, 1996). This could have made larger social networks more feasible, and created greater pressures for advanced social communication (Dunbar, 2004). However, a complex infrastructure that facilitates trust and material support within a group may have been necessary before symbolic communication was viable (Knight et al., 1995). 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 (Gibson et al., 1994; Kolodny et al., 2018), collaborative hunting (Sterelny, 2012), or the need to maintain sources of fire (Twomey, 2013). We also noted some links that, as far as we know, have not been remarked on in the literature: Knight et al.'s ritual theory involves beliefs about hunting; hunting animals provides bones that can be used as fuel for fires; fire is used to reduce predation risk.

The second finding is that, despite the interconnectedness, the majority of theories are not mutually exclusive. There are only two points of formal conflict in the causal graph. Firstly, Knight et al. do not think that gossip on its own can create effective alliances, in contrast to Dunbar. Secondly, Noble & Davidson suggest that symbolic language facilitates hunting, rather than the other way around. Finally, around half of the causal connections were hypothesized in the source papers without empirical support. This suggests there is much outstanding work

to make these theories robust. In order to accomplish this work, we need a practical testing method, for which Experimental Semiotics is a candidate.

3. Experimental semiotics

Experimental semiotics uses methods from psychology to explore the role of cognition, acquisition, and usage in shaping language (Galantucci, 2009; Roberts, 2017). Studies use lab-based experiments with human participants who must construct, use, and transmit artificial languages. These methods have been used to explore the emergence of compositional structure (Kirby et al., 2015). Initial results suggested that inter-generational transmission was a key causal property, but recent studies test whether the same pressure can be created by needing to communicate with a large population (Raviv, Meyer & Lev-Ari, 2019). Essentially, the experiments provide a way of comparing design solutions to the "common task" of creating conditions for the emergence of compositionality.

However, in order to obtain a high level of experimental control, these experiments tend to use very idealised tasks based on formal communication games, and impose strict limits on the ways that individuals can interact: one individual speaks at a time; pointing is only allowed during feedback; or individuals can't initiate repair (see Macuch Silva & Roberts, 2016). Irvine & Roberts (2016) noted that several experimental semiotics studies assume that the pressure to communicate derived from the need for individuals to collaborate in order to manipulate physical objects or build complex constructions. However, the experimental tasks are so constrained that they remove the possibility of any other strategies. We argue that a different kind of common task is needed to explore the origins of symbolic communication.

4. A common task framework for studying symbolic communication

A common task framework approach involves iterating on the solution of a practical task in order to understand how different pressures lead to different outcomes. For example, in the field of robotics, the *DARPA Grand Challenge* is a common task framework where an autonomous robotic vehicle must complete a task in the real world such as driving across a desert. Different robotic designs can be evaluated against each other according to how well they complete the task. While the DARPA Challenge focuses on designing robots, for studying the emergence of symbolic communication we suggest that the experimenter's task is to design a **situation** (including a physical **environment** and **survival task** that individuals must complete) that creates a pressure for individuals to develop a symbolic communication system. The effectiveness of the situation is tested by placing agents (with a capacity for symbolic communication, but no existing

conventions within the challenge context) into the situation and observing if they do indeed invent a symbolic communication system.

These situations may be somewhat abstract, but they should reflect relevant and plausible analogues of early hominid life. Using the causal graphs as a guide, different theories are translated into minimally contrasting situations. These situations are then tested (using human participants or simulated agents), and the results can be contrasted to evaluate the theories against each other. The aim of the common task framework is not to recreate the exact, true emergence of symbolic communication in human ancestors: we cannot know what this situation was. Instead the procedures are used as grounded thought experiments in order to explore and refine theories (e.g. Webb, 2000; Steels, 2003).

One candidate framework for studying the emergence of symbolic communication comes from Irvine & Roberts (2016). This was an experiment with two human participants in a 3D virtual world, using the video game *Minecraft*. The environment was a field outdoors, and the survival task was to build a shelter together. Each participant had half of the plan for the shelter, providing a reason to communicate. 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: they could use their virtual avatar to point and they could also knock on the table. This gave them the option of developing a simple symbolic system to refer to the four different building materials (e.g. one knock for red blocks, two knocks for yellow blocks etc.). That is, participants were placed in a similar situation to our pre-linguistic ancestors: they had the capacity to construct a symbol system, but the crucial question was whether the task would motivate them to do so. The results showed that all participants used pointing and trial-and-error strategies to successfully complete the task. Post-experiment interviews confirmed that there was not enough motivation to invent a symbolic system, and so none evolved. After all, setting up a symbolic system takes time, and the pointing strategy was productive enough to be successful. Irvine & Roberts concluded that the need to collaborate for construction would not have been a strong enough selective pressure to motivate the emergence of a symbolic system for our ancestors.

In summary, a pressure to develop a complex communication system relies on a particular practical situation. It might seem obvious that various theories would create a pressure for the emergence of symbolic communication. However, by putting the theory into practice, Irvine & Roberts realized that the opportunity cost of setting up a symbolic system is high, and participants may find unexpected

solutions that avoid having to do so. The question now is: what situations would motivate them to invest time in creating a symbolic system?

5. Candidate situations

Based on the causal review of the literature, we propose that situations which promote the emergence of symbolic communication will have various key properties. First, there will be an **asymmetry of information** between individuals. That is, some individuals will know facts or skills that the others do not, creating something to communicate about. A second property is that the referents to be communicated about will be **distant in time or space**, making pointing less effective. These first two properties are found in some advanced non-human communication systems, such as honey bees needing to communicate the location of pollen (von Frisch, 1967). Another key property is the need for **division of labour**. This requires coordination and scheduling between individuals, requiring trust and cooperation. Principles from video game design (Brown, 2018) suggest more key properties, including: **More tasks than people** to promote role-switching; **dead time** to promote multitasking; **disruptions** which change task demands to prevent ritualization of strategies; **public goods** to promote coordination of who does tasks with no direct reward. We predict that these key properties will emerge as common elements in successful situation designs. These will define a set of properties that solve the "meta-task" of promoting the emergence of symbolic communication.

There are two candidate situations motivated by anthropological theories that may meet these key properties. The first involves fire maintenance. Humans began using fire long before being able to create it (Twomey, 2013), and even today fire *making* technology is not universal in human societies (McCauley, Collard & Sandgathe, 2020). Keeping a fire lit and fuelled create strong pressures to organise and divide labour between individuals. This could provide the right pressure to start referring to distant locations (sources of fuel) or points in time (agreements about tending the fire). The situation also involves dead time, disruptions and public goods. Manipulations of this situation could include how far away and how sparsely distributed the fuel sources were. The most successful experimental conditions could then be compared to plausible scenarios of early hominids.

The second situation is collaborative hunting. Sterelny (2012) suggests that the potential rewards of hunting big game would provide pressures to cooperate and communicate. An asymmetry of information exists between skilled and unskilled hunters. Some hunting strategies involve different roles (e.g. flushing and ambushing), and these roles may require individuals to be out of sight of each other at key moments. This would create a need for division of labour and

referring to future times and distant places in order to plan the hunt. Conditions could vary the number of participants or the speed of the animal. Fast animals might encourage strategies involving stealth or splitting the group into different roles, requiring communication about locations, time and coordinated action. The core causal components of these candidate situations can be recreated in a common task framework. We note that *Minecraft* has various features that help with this: fire dynamics; hearths that require a constant supply of fuel; projectile weapons; and animals that can be 'hunted'. It also supports computational agents.

6. Discussion

We presented a common task framework approach to investigating the evolution of symbolic communication. Causal inference tools were used to formally relate theories and identify critical differences. These were used to design a common task framework to evaluate those theories against each other. We suggested that theories related to fire maintenance and collaborative hunting meet some key properties for the emergence of symbolic communication. Of course, insights from this approach need to be integrated with other findings, including the role of repeated actions leading to conventionalisation and differences in cognitive abilities between our ancestors and modern human participants.

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