How to create a human communication system: A theoretical model

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Abstract

Following a synthesis of naturalistic and experimental studies of language creation, we propose a theoretical model that describes the process through which human communication systems might arise and evolve. Three key processes are proposed that give rise to effective, efficient and shared human communication systems: 1) motivated signs that directly resemble their meaning facilitate cognitive alignment, improving communication success; 2) behavioral alignment onto an inventory of shared sign-to-meaning mappings bolsters cognitive alignment between interacting partners; 3) sign refinement, through interactive feedback, enhances the efficiency of the evolving communication system. By integrating the findings across a range of diverse studies, we propose a theoretical model of the process through which the earliest human communication systems might have arisen and evolved. Importantly, because our model is not bound to a single modality it can describe the creation of shared sign systems across a range of contexts, informing theories of language creation and evolution.

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How to create a human communication system: A theoretical model

'The world was once devoid of people; the world was once devoid of language'

- Hockett, 1978

We do not know how or when language first arose (Dediu & Levinson, 2013). Because our pre-linguistic ancestors no longer exist, we cannot know with certainty how the earliest human communication systems were created. This complex question has been addressed by investigators from a range of disciplines. For example, primatologists make inferences about the physical (pre-) adaptations for language that our last common ancestor may have had, and examine great ape communication in the absence of a fully-fledged language (for reviews see Deacon, 1998; Seyfarth, Cheney & Bergman, 2005; Fitch, 2005; Arbib, 2005; Arbib, Liebal & Pika, 2008). Paleoanthropologists, geneticists, and archaeologists examine the evidence for early language use through the excavation of human remains and cultural artefacts (for reviews see Hurford, 2007; Gibson & Tallerman, 2012), and computational linguists model the emergence of simple artificial languages using agent-based computer simulations (e.g., Kirby, 2001; Cangelosi & Parisi 2002; Gasser, 2004; Steels, 2011).

These findings are complemented by research studying the emergence of human communication systems in naturalistic and experimental settings. Naturalistic studies examine language creation and change in its natural habitat. For example, by observing the creation of Nicaraguan Sign Language, researchers have documented how people without a shared language collectively create a manual communication system (for a review see Goldin-Meadow, 2010). Developmental studies track the cognitive and social processes that drive language acquisition by infants (e.g., Rowe & Goldin-Meadow, 2009; Oudgenoeg-Paz, Volman & Leseman, 2012) and historical linguists

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examine language change over time (e.g., Lieberman, Michel, Jackson, Tang & Nowak, 2007; Atkinson, Meade, Venditti, Greenhill & Pagel, 2008; Pagel, Atkinson, Calude & Meade, 2013).

Experimental simulations of language creation, under controlled laboratory conditions and using modern humans, complement these approaches by testing cause-and-effect relationships between factors that are thought to be important to language creation, extension and evolution. For example, by studying how people create new labels for novel objects using their existing language, spoken language experiments study the factors important to language extension and change (e.g., Clark & Wilkes-Gibbs, 1986; Garrod & Anderson, 1987; Schober & Clark, 1989). Other experimental approaches examine the factors important to language creation and evolution. In these studies, participants are prohibited from using their existing language, and must instead create a new communication system from scratch (e.g., Galantucci, 2005; Garrod, Fay, Rogers, Walker & Swoboda, 2010; Perlman, Dale & Lupyan, 2015; Fay, Lister, Ellison & Goldin-Meadow, 2014; Roberts, Lewandowski & Galantucci, 2015).

In this paper, we first outline the proposed theoretical model of how simple human communication systems might have first arisen and evolved (Section 1). We then synthesize the findings of naturalistic and experimental studies that inform the proposed model (Sections 2-4).

1. Theoretical Model

The proposed model, shown in Figure 1, describes three key processes underlying the creation and evolution of human communication systems. The first process is the use of 'motivated' signs (i.e., signs that bear a non-arbitrary resemblance

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to their meaning) to bootstrap mutual understanding between people. Motivated signs fall into two basic categories; icons and indices (Pierce, 1931-1958). Icons directly resemble their meaning, in other words, they *look like* or *sound like* the meaning they represent. For example, a photograph of an apple is an iconic representation of that apple. Indexical signs bring their meaning to mind via natural association, for example, the smell of smoke is an index of fire (Fay, Arbib & Garrod, 2013). In contrast, non-motivated symbolic signs share an arbitrary association with their meaning, and therefore must be learned (Fay et al., 2013).

As Wescott (1971) noted, “iconicity is a relative rather than an absolute characteristic of any communication system… the only realistic question we can ask about a given form is not ‘Is it iconic?’ but rather ‘How iconic is it?’”. Following Wescott (1971), we consider signs to lie on a continuum that ranges from absolutely motivated to absolutely arbitrary. Icons lie closest to the ‘absolutely motivated’ end of the continuum. Symbols lie closer to the ‘absolutely arbitrary’ end. Indices are more motivated than symbols, but less motivated than icons, and therefore lie somewhere in between. Bearing this relative continuum in mind, we do not distinguish categorically between icons, indices or symbols. Rather, we use ‘motivated signs’ to refer to signs that bear a more non-arbitrary resemblance to their referent, and ‘non-motivated’ signs to refer to signs that bear a more arbitrarily relationship to their referent. We regard all signs as varying in their degree of motivation, lying on a continuum between these two extremes.

Because motivated signs share a non-arbitrary resemblance to their meaning, they are able to bridge the gap between form and meaning (Fay et al., 2013), making it easier for people to understand a sign’s meaning on first encounter. After all, it is easier

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to interpret the meaning of a sign if it *looks like* or *sounds like* what it represents. We therefore argue that motivated sign production is the first step in establishing mutual understanding between people. In our model, we refer to mutual understanding between people as *cognitive alignment*. Successful communication occurs when people are cognitively aligned as both parties share the same underlying interpretation of the sign's meaning. Motivated sign production is a crucial first step to enable successful interpersonal communication. This is reflected in our model (Figure 1), in which a unidirectional arrow leads from 'motivated sign production' to 'cognitive alignment'. A one-way arrow is used to capture the causal relationship between sign motivation and cognitive alignment.

Behaviour alignment between interacting people (or behaviour matching) is the second key process in our model. Behaviour alignment is the tendency, over repeated interactions, for people to use the same sign-to-meaning mappings as their partner (e.g., Garrod & Anderson, 1987; Clark & Wilkes-Gibbs, 1986; 1992). Behaviour alignment is argued to enhance cognitive alignment (Pickering & Garrod, 2004). Aligning upon a shared inventory of sign-to-meaning mappings also minimizes cognitive effort; rather than storing two inventories of sign-to-meaning mappings (yours and your partner's) you need only store a single shared inventory. In our model, behaviour alignment upon a shared inventory of signs enhances cognitive alignment, improving communication success.

We also argue that behaviour alignment and cognitive alignment are mutually reinforcing, with behaviour alignment reinforcing cognitive alignment, and cognitive alignment reinforcing behaviour alignment. It can of course happen that people align their behavior without being cognitively aligned. For example, two people may align

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upon the phrase ‘the neighbour’s dog’, each unaware that their partner has a different neighbour and a different dog in mind. However, we suspect that this is relatively atypical, and that typically behavioral alignment is a proxy for cognitive alignment, as per Pickering and Garrod (2004). The mutually reinforcing nature of cognitive alignment and behaviour alignment is reflected in our model, where bidirectional arrows connect ‘behaviour alignment’ and ‘cognitive alignment’.

The third key process in our model is sign refinement and symbolization. Sign refinement gives rise to signs that are simpler and easier to produce (for example in spoken language, the sign ‘going to’ is often refined to ‘gonna’). This enhances the efficiency of the evolving communication system (e.g., Clark & Wilkes-Gibbs, 1986; Clark & Brennan, 1991), and causes the initially motivated signs to become increasingly symbolic. In our model, we argue that moment-to-moment partner feedback (e.g., requesting clarification or indicating comprehension) drives sign refinement, and that this increases the efficiency of the evolving communication system.

In the model proposed, sign refinement follows cognitive alignment. This is reflected by the uni-directional arrow from ‘cognitive alignment’ to ‘sign refinement’. Once interacting partners are cognitively aligned, subsequent sign refinement improves the efficiency of the evolving communication system. As the signs are increasingly refined, partners continue to behaviorally align their signs. This process maintains and reinforces cogntive alignment onto an inventory of increasingly simple symbolic signs. The arrows from ‘sign refinement’ to ‘behavioural alignment’, and ‘behaviour alignment’ to ‘cognitive alignment’ capture this dynamic process.

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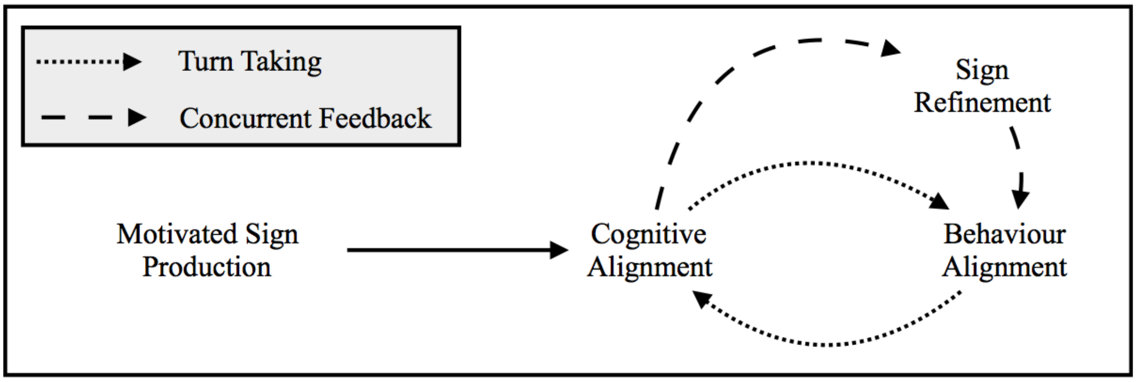

Figure 1. Model of sign creation and evolution: Motivated signs facilitate cognitive alignment; behaviour alignment (indicated by the dotted lines) reinforces cognitive alignment and drives the creation of an inventory of shared sign-to-meaning mappings; concurrent partner feedback (indicated by the dashed lines) drives sign refinement, making communication more efficient.

This paper is structured around a discussion of each of the three processes described and the evidence supporting its inclusion in the model. In Section 2, we review the evidence that motivated signs facilitate cognitive alignment, enabling new human communication systems to get started. In Section 3, we review studies demonstrating that behaviour alignment enhances cognitive alignment. In Section 4, we review the evidence that partner feedback improves sign efficiency and leads to the emergence of symbolic signs.

2. Process 1: Motivated Signs Get Communication Systems Started

A fundamental requirement of a communication system is that it can be understood. In modern language, where the relationship between forms and meanings is arbitrary (Saussure, 1916), one way to understand the meanings of novel symbols is to define them in terms of our pre-existing symbols (e.g., definitions in dictionaries). For

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example, the words ‘dog’ and ‘chien’ are arbitrarily related to their meaning. A language user who is unfamiliar with the sign ‘dog’ can be taught its meaning using a description in their pre-existing language (e.g., ‘a hairy four-legged animal’). It would be much more difficult, however, to use this method to teach novel symbols to a baby or child, whose pre-existing language is too sparse or rudimentary to comprehend such definitions. This begs the question of how our ancestors were able to produce mutually intelligible signs when they had no pre-existing language through which to define them. Harnad (1990) describes this as the *Symbol Grounding Problem*. He argues that, for our ancestors, bootstrapping a symbolic communication system like the one we use today would have been near-impossible.

A potential solution to the *Symbol Grounding Problem* is an ability to produce motivated signs that share a non-arbitrary relationship with their meaning (Perniss, Thompson, & Vigliocco, 2010; Perniss & Vigliocco, 2014; Imai & Kita, 2014). Because they bring their meaning to mind, either through direct resemblance (icons) or natural association (indices), motivated signs may act as a bridge between form and meaning (Perniss & Vigliocco, 2014). In our model, the production of motivated signs is the first step in language creation. Motivated signs facilitate cognitive alignment (i.e., mutual understanding), thereby helping to bootstrap successful communication.

Naturalistic studies indicate that motivated signs help communication systems get started. For instance, while the words of modern spoken languages are arbitrarily linked to their meaning, words learnt earlier in development, such as onomatopoeic animal noises (e.g., ‘moo’) are more motivated relative to words learnt later in development (Monaghan, Shillcock, Christiansen & Kirby, 2014; Imai & Kita, 2014; Perry et al., 2015). This indicates that motivated signs facilitate language acquisition.

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The same pattern is observed in gesture-based communication: children are faster to learn motivated hand signs than symbolic ones (Bohn, Call & Tomasello, 2016), and new signers are better at learning motivated manual signs compared to non-motivated manual signs (Baus, Carreiras & Emmorey, 2013).

When adults create novel communication systems in the lab, they begin by producing motivated signs (e.g., Garrod, Fay, Lee, Oberlander & MacLeod, 2007; Fay, Garrod & Roberts, 2008). Garrod et al.'s (2007) *Pictionary* study provides a concrete example of how motivated signs help bootstrap human communication systems (see Figure 2). In this study, pairs of participants try to communicate a range of recurring meanings to a partner over six games. Like the game *Pictionary*, participants communicate by drawing on a virtual whiteboard, but are prohibited from using conventional language (spoken or written). On each game, one participant (the Director) tries to communicate a list of meanings to their partner (the Matcher). The Matcher has the same list of meanings (in a different order) and tries to note down the order in which each meaning was communicated by the director. Matchers are allowed to interact with Directors during each game by drawing on the whiteboard in a different coloured ink (e.g., in Figure 2 the Matcher has made additions in green ink at Game 1). Participants alternate directing and matching roles from game-to-game (for a review of Pictionary-type studies see Fay, Ellison & Garrod, 2014. As Figure 2 shows, in early games (especially Games 1 and 2), the participants use motivated signs (i.e., detailed drawings of a figure thinking of a house) to communicate 'homesick'. Because participants can interact within games, at Game 1, the Matcher is able to annotate the Director's drawing (adding a sad expression to the figure's face) to clarify the meaning of the sign. During later games, the signs lose much of their detail, and by Games 5 and 6 the signs used to

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communicate ‘homesick’ are mostly symbolic; the human figure is absent and the house has been simplified to the point where it barely resembles a house (the door and windows are now absent).

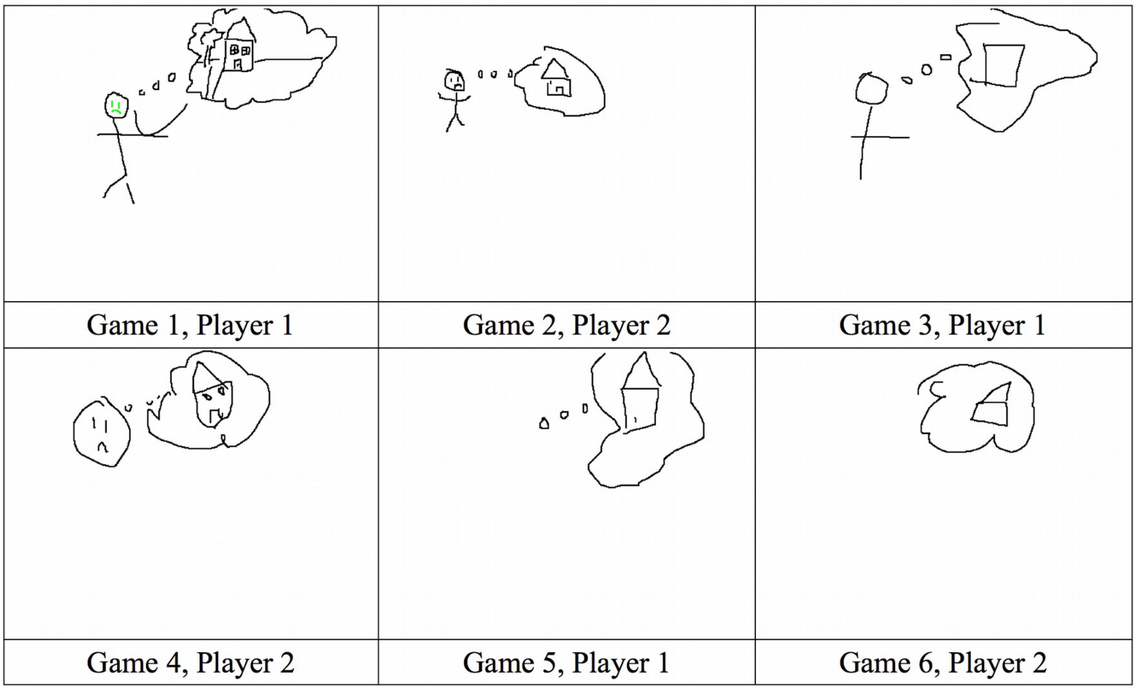

Figure 2. Signs produced by a pair of participants communicating ‘homesick’ (from Garrod et al., 2007). The green ink at Game 1 represents the Matcher’s annotations during within-trial interaction. Early drawings (games 1-2) are detailed and motivated, showing a figure thinking of a house. Later drawings (games 5-6) are simpler and more symbolic; the human figure is absent, as are important house features, such as the door and windows. Across games, participants demonstrate behaviour alignment and sign symbolization: their signs become more similar and simpler.

Compared to vocal communication, gesture more naturally lends itself to the production of motivated signs. For example, it is easier to imagine how to create a motivated sign for the meanings ‘running’, ‘tired’ or ‘apple’ by gesture than by non-

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lexical vocalization (making sounds that are not words). If correct, it follows that gesture will be a better means of bootstrapping a human communication system compared to non-lexical vocalization. This was tested by Fay et al (2013, 2014). They compared communication in these two modalities, and predicted that participants would be more successful at bootstrapping a novel communication system through gesture than through vocalization. They had participants play a ‘charades game’ that prohibited the use of the participants’ pre-existing language, limiting communication to gestures or non-lexical vocalizations. Their results confirmed the hypothesis: participants who gestured were more successful at communicating a range of different meanings (emotion, action and object words) to a partner, compared to those who relied solely on vocalizations. These findings suggest that motivated signs help new communication systems get started because they facilitate mutual understanding (i.e., cognitive alignment).

Although Fay et al. (2013; 2014) demonstrated a benefit of gesture over non-lexical vocalization for bootstrapping human communication, they did not measure sign motivation. To examine the relationship between sign motivation and communication success, Lister, Fay, Ellison, & Ohan (2015) ran a similar study with a larger range of meanings (over 1000 nouns, verbs and adjectives), and had judges rate the degree of motivation for each sign. They predicted that gestures would be more motivated than vocalizations, arguing that that this is why gestures are better suited to language creation compared to vocalization. Each sign was rated on a Likert scale from 0 (not at all motivated) to 6 (highly motivated).

Gestured signs were rated as more motivated than vocal signs. The distribution in the ratings of sign motivation for gestural and vocal signs is shown in Figure 3. As

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the figure shows, gestured signs tended to be rated as more motivated than vocal signs. As per Fay et al. (2013; 2014), participants who used gesture to communicate were more successfully than participants who used vocalization to communicate (i.e., they demonstrated greater cognitive alignment). Moreover, across both modalities, signs that were rated as more motivated tended to be guessed correctly by the matcher (see also Perlman et al., 2015 for a similar pattern of results in the vocal-only modality). This finding demonstrates a direct link between sign motivation and cognitive alignment. In addition, these findings are complemented by studies showing that when motivated sign production is impeded, communication success decreases (e.g., Galantucci, 2005; Scott-Phillips, Kirby & Ritchie, 2009; Roberts, 2015).

In summary, motivated signs help bootstrap human communication systems. This is reflected in our model, in which motivated sign production is the first step and is directly linked to cognitive alignment. In the model, a unidirectional arrow connects

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‘motivated sign production’ to ‘cognitive alignment’.

Figure 3. Distribution of sign motivation ratings for signs produced by gesture or by non-lexical vocalization. A rating of 0 indicates no sign motivation (i.e., symbolic) and a rating of 6 indicates high sign motivation (i.e., iconic).

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3. Process 2: Behaviour Alignment Enhances Cognitive Alignment

How do sign systems become shared? We argue that people align their signs over repeated interactions. Interactive behaviour matching (i.e., behaviour alignment) leads to a shared communication system in which people use the same signs to communicate the same meanings. Figure 2 illustrates behaviour alignment between participants in Garrod et al.'s (2007) graphical communication task. The pair aligns upon increasingly similar signs to represent the meaning 'homesick' across games.

Behaviour alignment upon a shared sign system enhances cognitive alignment (communication success), and reduces cognitive effort because people only need to recall one set of sign-to-meaning mappings, as opposed to remembering both their set, and their partner's set. This process is captured by our model: once people understand each other (cognitive alignment), they then align behaviourally, using the same signs to communicate the same meanings. Behaviour alignment gives rise to a shared inventory of signs, and this reinforces cognitive alignment. Bi-directional arrows connect 'cognitive alignment' and 'behaviour alignment' because these processes are mutually reinforcing in our model.

What is the benefit of behaviour alignment? Garrod and Pickering (2004) suggest that people align their linguistic behaviour because it makes conversation easier. If you and your partner use the same signs to communicate the same meanings, it is likely that you also share similar mental representations (i.e., you are cognitively aligned). This frees people from having to repeatedly infer their partner's brain state – they can assume it is the same as their own (Pickering & Garrod, 2004). In this way, behavior alignment facilitates cognitive alignment. Experimental simulations support

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this suggestion. When interacting participants use the same signs to communicate the same meanings, they enjoy more successful communication. This is seen in tasks in which participants communicate using their pre-existing language (e.g., Fusaroli, Bahrami, Olsen et al. 2012), and in tasks in which participants must create new communication systems from scratch; by drawing (e.g., Galantucci, 2005; Garrod et al., 2007; Fay, Garrod, Roberts & Swoboda, 2010), by gesture (e.g., Fay et al., 2013; 2014; Lister et al., 2015), or by vocalization (e.g., Perlman et al., 2015; Perlman & Cain, 2016).

These studies indicate a correlation between behaviour alignment and cognitive alignment, but do not speak to the causal role of behaviour alignment on cognitive alignment. This was examined by Fay et al. (under revision) using a Pictionary-type task. Pairs of participants took turns communicating a range of experimenter-specified meanings to their partner over a virtual whiteboard. However, one group of participants was instructed not to copy their partner's signs, thereby eliminating the opportunity for behavior alignment. As predicted, pairs who were prevented from aligning their signs demonstrated lower cognitive alignment compared to pairs of participants permitted to align their signs. This study demonstrates a causal relationship between behaviour alignment and cognitive alignment, such that behaviour alignment drives cognitive alignment.

In our model, we propose that causality operates in both directions, i.e., that behaviour alignment drives cognitive alignment and cognitive alignment drives behaviour alignment. With regards to the latter, one must at least partially understand the meaning of the sign produced by their partner if they are to reuse that sign to communicate the same meaning. Thus, we argue that a mutually reinforcing

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relationship develops between behaviour alignment and cognitive alignment, with cognitive alignment driving behaviour alignment, and behaviour alignment driving cognitive alignment. This relationship is reflected in the bidirectional arrows connecting ‘behaviour alignment’ and ‘cognitive alignment’ in our model.

4. Process 3: Sign refinement drives symbolization

In Section 2, we argued that motivated signs help ground shared meanings when creating a novel communication system. However, a review of modern languages indicates that signs do not remain motivated. Even signed languages, regarded as highly motivated communication systems, undergo symbolization and become less motivated over time (Bellugi & Klima, 1976; Sandler, Aronoff, Meir, & Padden, 2011). Peirce (1931–1958, Vol. 2, p. 302) suggested that symbols arise out of preexisting motivated signs, such as icons. What drives sign symbolization, and what are the benefits of symbols over motivated signs?

The transition from motivated signs to symbolic signs has been observed in a range of contexts. For instance, since its inception in 1816, American Sign Language signs have gradually lost their motivation and become increasingly symbolic (Frishberg, 1975). Similarly, early written scripts (e.g., early Egyptian, ancient Chinese, Sumerian) are more motivated compared to later, more symbolic versions (Wescott, 1971). Westcott (1971) notes that the older a script is, the more motivated it tends to appear (for example, Roman numerals are more motivated than Arabic numerals). If you look back far enough, Wescott (1971) argues, you can uncover the motivated roots of many language systems. For instance, in our modern alphabet, ‘A’ derives from an earlier sign, ‘’, which depicted a horned ox head (Wescott, 1971).

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A similar icon-to-symbol transition has been observed in experimental studies. In spoken language studies, participants' object descriptions become more succinct and less motivated over repeated interactions. For instance, in Clark & Wilkes-Gibbs' (1986) study, participants repeatedly described a variety of geometric shapes to a partner. Initially, participants used elaborate figural descriptions to communicate the shapes, but over repeated interactions the object descriptions became more succinct and abstract. For example, ''[it] looks like a person who's ice skating, except they're sticking two arms out in front' became 'the ice skater' over repeated interactions (for similar results, see Garrod & Anderson, 1987). The same pattern is evident in the example from the graphical communication task shown in Figure 2. Over repeated interactions, the motivated signs became simpler and more symbolic. This icon-to-symbol transition has been widely replicated in a range of graphical referential communication tasks (e.g., Healey, Swoboda, Umata & Katagiri, 2002; Garrod et al., 2007; Fay et al., 2008; Theisen, Oberlander & Kirby, 2010; Fay & Ellison, 2013). While motivated signs help bootstrap human communication systems, the signs invariably shift towards arbitrariness over time.

What drives this transition from motivated signs to arbitrary signs? In our model concurrent partner feedback (i.e., moment-to-moment feedback between Director and Matcher) drives sign refinement. We suggest that sign symbolization occurs as a consequence of this interactive feedback. As signs become simpler (refinement), they are stripped of elements that are non-essential to conveying their meaning (Garrod et al., 2007). The less information contained in the sign, the fewer iconic or indexical elements it can possess, so motivation decreases. This causes the signs to become more arbitrary over time.

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Support for these processes comes from Garrod et al. (2007), who highlighted the importance of concurrent partner feedback to the refinement and symbolization of emerging communication systems. In their graphical referential communication task, they manipulated partner feedback such that matchers could or could not provide concurrent feedback to the director. Garrod et al. (2007) found that participants who were allowed to interact directly and provide concurrent feedback produced increasingly refined and symbolic signs over games. By contrast, directors who did not receive feedback from their partner produced signs that became increasingly complex across games. These findings demonstrate the importance of moment-to-moment interactive feedback between partners when refining and symbolizing an emerging communication system. A similar pattern of results is returned by Fay et al. (under revision). In addition, similar results are seen in verbal referential communication studies (e.g., Schober & Clark, 1989; Hupet & Chantraine, 1992; Brennan & Clark, 1996; Bavelas, Coates & Johnson, 2000; Fusaroli et al., 2012). Together, these studies convincingly demonstrate that concurrent feedback is crucial to sign refinement. As the signs are refined they become more symbolic, leading to an increasingly efficient and arbitrary communication system.

What is the benefit of transitioning from motivated signs to more symbolic signs? We suggest two benefits. First, it makes communication more efficient. The principle of least collaborative effort (Clark & Wilkes-Gibbs, 1986) suggests people tend to develop communication systems that require minimum effort to process. Simple signs require less cognitive effort to produce and perceive, thus, once people understand each other, it is beneficial for them to simplify their signs to reduce their collaborative effort. Second, transitioning to a more symbolic signs facilitates lexicon expansion

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(Perniss et al., 2010). In symbolic spoken languages, we can make fine-grained distinctions between semantically related concepts (e.g., ‘running’, ‘jogging’, ‘sprinting’). Semantically related concepts would be harder to distinguish using motivated signs as motivated signs for similar meanings will look or sound similar. Computer simulations show that motivated signs are most useful when there is a small lexicon, and therefore a low chance of producing confusable signs (Gasser, 2004), but as the lexicon expands, arbitrary signs are preferred. We argue that a pressure to communicate efficiently, plus the opportunity for lexicon expansion, is facilitated by sign refinement and symbolization.

Our model captures the transition from motivated sign to symbol through sign refinement. An arrow leads from ‘cognitive alignment’ to ‘sign refinement’ to show that once interacting partners have cognitively aligned, their sign system does not need to remain motivated, and can then be refined and become more symbolic. As each sign is refined, partners continue to align upon the simplified sign. This is reflected by the arrow that leads from ‘sign refinement’ to ‘behaviour alignment’. Sign refinement relies on concurrent partner feedback, which is indicated by the dotted lines. Thus, concurrent partner feedback enhances the efficiency of the communication system through the refinement and symbolization of the signs.

5. Conclusion

We propose an empirically derived theoretical model that describes how simple human communication systems arise and evolve through social interaction. We describe three key processes that contribute to the evolution of shared, symbolic sign systems. First, motivated signs allow people to directly link form to meaning. This helps

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bootstrap communication by enabling interacting partners to understand each other. Second, once mutual understanding is established (cognitive alignment) people tend to align their signs (behaviour alignment), leading to a shared inventory of sign-to-meaning mappings. In addition, behaviour alignment reinforces cognitive alignment. Third, after mutual understanding is established, people tend to refine and symbolize their initially motivated signs. This process improves the efficiency of the evolving communication system, and facilitates lexicon expansion. Together, these processes allow new sign systems to be created, and to become shared and efficient. In other words, through these processes communication systems become functionally adapted for use.

The emergence of communication systems is widely researched, however there is currently no big-picture model of the basic processes underpinning sign creation and evolution. Through our synthesis of the literature, we have developed a theoretical model that captures these processes. Because it is not bound to a single modality, the model allows us to describe the creation of sign systems more generally, and helps conceptualise language evolution across a range of contexts.

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