4 A Complex-Adaptive-Systems Approach to the Evolution of Language and the Brain

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1 Introduction

Language has arguably been as important to our species' evolutionary success as has any other behavior. Understanding how language evolved is therefore one of the most interesting questions in evolutionary biology. Part of this story involves understanding the evolutionary changes in our biology, particularly our brain. However, these changes cannot themselves be understood independent of the behavioral effects they made possible. The complexity of our inner mental world – what will here be referred to as *conceptual complexity* – is one critical result of the evolution of our brain, and it will be argued that this has in turn led to the evolution of language structure via cultural mechanisms (many of which remain opaque and hidden from our conscious awareness). From this perspective, the complexity of language is the result of the evolution of complexity in brain circuits underlying our conceptual awareness. However, because individual brains mature in the context of an intensely interactive social existence – one that is typical of primates generally but is taken to an unprecedented level among modern humans – cultural evolution of language has itself contributed to a richer conceptual world. This in turn has produced evolutionary pressures to enhance brain circuits primed to learn such complexity. The dynamics of language evolution, involving brain/behavior co-evolution in this way, make it a prime example of what have been called "complex adaptive systems" (Beckner et al. 2009).

Complex adaptive systems are phenomena that result from the interaction of many individual components as they adapt and learn from each other (Holland 2006). They have in common the emergence of interesting higher-level patterns that do not initially appear obvious given the behavior of individual actors in the system. Classic examples of complex adaptive systems are ant colonies, in which the behavior of the colony as a whole is highly intelligent, flexible and adaptive, even though the colony itself is composed exclusively of individuals with very simple, rigidly stereotyped behavior (Holland 1998). Those that take the view that "the mind is what the brain does" are essentially making the same kind of argument: the action of each neuron is very simple, and no single neuron "knows" anything about the mind, yet the sum of their actions *is* the mind. From a complex adaptive systems perspective, it is a mistake to assume that the patterns and behaviors of the whole system are *in* each individual agent. Instead, the patterns emerge from the sum of actions of sets of adaptively interacting agents and are therefore more properly understood as existing between agents.

The argument here will be that language is similarly not the result of neural circuits innately coded in the mind of each individual, but instead that these patterns are the result of complex interactions at three levels: biological evolution, cultural evolution, and the ontogenetic development of individuals. The complexity of language is the result of a biocultural evolutionary process, or one that is neither exclusively biological nor exclusively cultural (Christiansen & Chater 2008; Evans & Levinson 2009). In particular, it will be argued that the patterns of language use – grammar and, more specifically, syntax – are more properly understood as being emergent characteristics of increasing conceptual complexity of individuals who are embedded in an intensely socially interactive (i.e., communicative) existence (Savage-Rumbaugh & Rumbaugh 1993; Schoenemann 1999). This intense social interactivity is a legacy of our being primates and long predates the origin of our species – let alone language.

The complexity of language has been studied from a variety of perspectives in linguistics. One dominant view, identified with Noam Chomsky and followers (e.g., Chomsky 1972; Jackendoff 2002; Pinker & Jackendoff 2005), has been that linguistic complexity is best understood as the result of some formal (logical) model, with the assumption being that a correctly described model will be innately instantiated in the brain in some way. There is no doubt that regularities exist in specific languages. Whether there are truly any language universals *across* languages, however, has been called into question (Evans & Levinson 2009). The complexity and fuzziness of the phonological systems within and between languages is so great that even the basic assumption that speech can appropriately be divided into discrete packages (called phonemes) has been called into question (Port 2010; Port & Leary 2005). Furthermore, those who believe in Universal Grammar do not agree about exactly what formal model best describes language. Chomsky's own models have notoriously changed a great deal over the past half-century, with the latest incarnation emphasizing a so-called "minimalist" view of the underlying cognitive mechanisms (Chomsky 1995). However, the minimalist program has been criticized by other formalists (e.g., Pinker & Jackendoff 2005), highlighting the lack of agreement about what such a model of language should look like even among linguists subscribing to Chomsky's general approach.

In any case, the goal in some areas of linguistics has been to try to understand language complexity on its own terms, assuming that this could be validly studied independent of how the brain actually works and that language structures so derived would then necessarily be evident in the brain in some fashion. Language complexity has also usually been studied without a deep understanding of how the evolutionary process has led to various other kinds of behavioral change. This lack of evolutionary grounding is particularly unfortunate, because language did in fact evolve, and, as a consequence, any model of language complexity that is not easily explained from an evolutionary perspective cannot then be considered a legitimate model of language itself (Schoenemann 1999). Understanding the complexity of language necessitates understanding how the brain works in creating meaning, within the context of how the evolutionary process would mold both brain and language.

2 Constraints on Language Adaptation

The evolutionary changes that occurred in our lineage to make language universal are presumably the result of natural selection (Pinker & Bloom 1990). For natural selection to operate, however, there must be some environmental influence favoring these changes. The environment relevant to language ability is the social environment, which is of course made up of interacting individuals. Evolutionary changes relevant to language will only be beneficial to an individual to the extent that they help that individual communicate better with others. This in turn presumes that these other individuals already have similar enough abilities to begin with (before selection operates), such that any new changes introduced by one individual will actually increase this individual's communication ability with others. This dynamic constrains the possible ways in which evolutionary change can occur, constantly biasing changes toward modifications of pre-existing abilities. This in turn predicts that language will have been built on a cognitive foundation that we share with other species, and furthermore that these foundations should still be evident. One critical component of this foundation is conceptual understanding: how we perceive, experience and make sense of the world. Aspects of this conceptual understanding are, of course, exactly what we are trying to share and communicate with others using language.

3 Types of Complexity

In order to assess complexity in language systems, it is important to define what we mean by "complexity." One place to look for such a definition is in the field of Complexity Theory, where a number of definitions have been proposed (e.g., Horgan 1995; Mikulecky 2001). A system in a high degree of disorder (i.e., having high entropy) is, in some sense, complex, but it is not necessarily complex in a particularly interesting way (Horgan 1995). One popular notion in the field has been that the most interestingly complex systems exist at "the edge of chaos" (Langton 1990), somewhere between complete chaos and complete order. Langton argued that systems in such a state are the most potentially useful for computation (Langton 1990), though subsequent work has not particularly supported this idea (Mitchell et al. 1993).

One intriguing suggestion is that complexity should be understood as "the property of a real world system that is manifest in the inability of any one formalism being adequate to capture all its properties" (Mikulecky 2001: p. 344). This definition fits nicely with the observation that it has so far been impossible to find a single formalism, even among committed formalists, that describes the patterns of language grammar to everyone's satisfaction (Pinker & Jackendoff 2005). If instead we view language as the result of a complex adaptive system, in which interacting biological and cultural evolutionary systems – each with their own constraints, influences, and partly interdependent histories – conspire over evolutionary time to produce a system of communication, the problem of language evolution becomes tractable.

Mikulecky (2001) suggests that the phenomenon of "emergence" seen in complex adaptive systems may simply be "a result of the limits of a dominant formalism" (p. 344). In other words, perhaps it is our fascination with trying to box complex systems into single formal models that leads to our surprise at the "emergent" behavior of these systems. If we view language evolution as the result of a complex interplay of influences of different kinds (each described, imperfectly, by their own unique formalisms), the emergence of language becomes much less miraculous.

For the purposes of this chapter, we will emphasize the following senses of complexity:

1) number of different kinds of individual things (actions, objects, etc.);
2) number of individual interactions between things;
3) number of *types* of interactions between things; and
4) levels of hierarchical interaction between sets of things.

4 Conceptual Complexity

What exactly is meant by conceptual complexity? It can be understood to be a function of: (1) the number of different dimensions the brain can meaningfully distinguish, and (2) the number of possible interactions between these dimensions (Schoenemann 2010). "Meaningfully distinguish" in this context may be defined as any internally detectable difference in pattern(s) of brain activation (whether caused by external stimuli or by internal neural activity); and "dimensions" may be defined as aspects of reality that the brain is sensitive to (e.g., wavelengths of light, types of molecules, temperature, etc.) or internally creates (e.g., emotions, patterns of thought, etc.). One can imagine that there are organisms that have a much simpler conceptual understanding of the world than we do. Some invertebrates such as jellyfish, for example, do not have eyes that produce images, but rather have very simple light-sensitive eyespots ("pigment spot ocelli") that simply detect light coming from a particular direction (Hudson 2010). This suggests a very simple conceptual awareness of visual information, vastly simpler than what humans (and most vertebrates) have available.

5 The Neural Basis of Concepts

To understand why a comparative cross-species assessment of brain structure could imply something important about likely degrees of conceptual complexity, it is important to understand how concepts are instantiated in the brain. Neural processing is thought to be the result of networks of neurons in different states or temporal patterns of activation (Baars & Gage 2007). The brain is organized with a degree of regional specialization of function. The cortex itself, which is the seat of conscious awareness (in humans at least), is divided up into different regions that specialize, to one degree or another, in particular types of processing (Baars & Gage 2007). The characteristics of the neural circuitry in different regions ("cytoarchitecture") differ enough to be reasonably identifiable across individuals, forming the basis for the identification of specific brain regions. These cytoarchitectural characteristics led the early neuroanatomist Brodmann (1909) to suggest a classification scheme for cortical areas (called "Brodmann areas") that is still used to this day.

The details of what exactly each of these cytoarchitectural areas does, and how they interact, is by no means completely understood, but there are well-studied pathways that are known to specialize in different kinds of information (Baars & Gage 2007). For example, it is possible to distinguish separate areas and neural pathways specialized for visual, auditory, somatosensory (i.e., touch, temperature, pain), olfactory, and taste information. Within these, there are typically further subdivisions of function. For example, cortical processing of visual information starts in the primary visual cortex in the occipital lobe (at the far back of the brain), but then divides approximately into (1) a dorsal "where" pathway (extending superiorly into the parietal lobe) that specializes in movement and spatial aspects of visual information, and (2) a ventral "what" pathway (extending anteriorly into the temporal lobe) that specializes in object identification (Baars & Gage 2007).

To be sure, there are additional areas and pathways that integrate this information in various ways, and basic sensory processing in one sensory domain can affect basic sensory processing in another domain, such that these primary areas are not completely independent of each other. One very nice example of this is the McGurk effect (McGurk & MacDonald 1976), where the basic auditory perception of a syllable (e.g., *ba*) is fundamentally changed by concurrent visual input of someone saying a different syllable (e.g., *ga*). Nevertheless, there are areas known as primary sensory areas that are known to specialize in the processing of specific types of sensory information.

Very simple concepts, like colors, smells or tastes, are thought to be the result of particular patterns of neural processing within different primary sensory areas that combine different types of signals from external sensors. The retina of the eye, for example, has cells that are tuned to respond to particular wavelengths of light. Different colors are distinguished by different patterns of stimulation of sets of these basic retinal cells. More complex concepts are, at some level, based on patterns of activation of different networks subserving often very different kinds of information. The concept of coffee, for example, binds together a number of sensory components, involving not only taste and smell, but also – for many people – visual components (e.g., shape and color of coffee beans), somatosensory components (e.g., warmth of the fluid, physical features of the cup typically used to drink it), and even more abstract components, such as the sense of well-being that many feel as a result of drinking it (Damasio & Damasio 1992).

There remains some question over how concepts are actually represented in the brain at the neural level. One suggestion is that there are specific individual neurons that represent specific concepts. Such hypothetical neurons are usually referred to as "grandmother cells" (after a tongue-in-cheek parable by the neurobiologist Jerry Lettvin that introduced the term; Gross 2002). The idea of individual concept-specific neurons is a logical extension of work on how the visual system identifies objects (Gross 2002). At the level of the retina, individual ganglion cells are sensitive to the activity of specific, very simple patterns of photoreceptor cells: for example, a small spot of light surrounded by darkness. A straight line can therefore be detected as the coincident activation of a unique set of these "spot detector" ganglion cells. This coincident activation can be detected by a single neuron that fires only when the unique set of ganglion cells are also active (for a basic discussion see Goldsmith & Zimmerman 2000). Such a neuron would be the neural representation of a line (a simple concept).

However, note that for such a "line detector" neuron to be activated, a network of retinal ganglion neurons must also have been activated. For increasingly complicated, subtle, and interesting concepts, larger and larger networks of neural activity will be involved, connecting regions specializing in processing different kinds of information relevant to those concepts. Whether unique "grandmother cells" (or even specialized networks that we might call "grandmother circuits") actually exist for more complicated concepts, and if so, whether these should be considered the neural instantiations of concepts, is not critical for the argument here. The important point is that networks of brain activation form the foundation for concepts in the brain.

Congruent with this, Barsalou (2010) has argued that the "core representations in cognition" – what we are calling here "concepts" – are not "amodal data structures that exist independently of the brain's modal [basic sensory] systems," but are instead fundamentally grounded in "the environment, situations, the body, and simulations in the brain's modal systems" (p. 717). He refers to this as "grounded cognition," and notes a number of perspectives that support this idea. Lakoff and Johnson's (1980) analysis of linguistic metaphors led them to argue that abstract concepts are specifically grounded in bodily experience. Gibson's (1979) work on visual perception led him to argue the external environment plays a fundamental role in perception. Work by Paivio (1971), Shepard and Cooper (1982), and Kosslyn (1980) suggested that mental imagery was important to perceptual representations. Studies of brain activity while subjects are simply imagining an object (that is not actually present) have shown that the same areas are activated as when the object *is* actually being viewed (Damasio et al. 1993; Kosslyn et al. 1993; Kosslyn et al. 2003). All of this is consistent with the idea that conceptual understanding is grounded in basic perceptual information.

It is also important to note that at least some basic conceptual understanding seems to be instantiated in brains independent of one's language. For example, Le Clec'H et al. (2000) showed that for bilingual subjects the same specific brain networks for particular concepts (i.e., number processing vs. body-part processing) appeared to be activated regardless of the language used. This is consistent with the idea that languages map onto underlying conceptual networks in the brain.

Because of the difficulties of doing brain scanning in awake primates, little work has been done outside of humans with respect to the neural instantiation of concepts. However, there is evidence that grounded cognition holds across species as well (Barsalou 2005). A study of brain activation in Rhesus macaques (*Macaca mulatta*) showed that species-specific social calls resulted in increased brain activation in auditory processing areas, visual areas, areas of the temporal lobe associated with facial expression and visual motion, and emotion-processing areas (ventro-medial prefrontal cortex, amygdala, hippocampus), as compared to activation recorded while hearing unfamiliar sounds (Gil-da-Costa et al. 2006). Thus, simply hearing socially relevant auditory input led to increased activation in monkeys in a whole range of other areas known to be involved in social information processing.

All of this suggests that the more complex a concept is, the greater the number of distinct brain networks will be activated either concurrently or temporally in a causal manner. Thus, we may understand conceptual complexity as a function of the number of differentiable network activation states of a brain (with the understanding that some sets of physically unique network activation states may be functionally equivalent – i.e., will not be differentiable – because they do not make a difference to the organism's awareness). This notion is congruent with Tononi's definition of consciousness as being simply the integration of information from different areas of the brain, and therefore a function of effective connectivity (Tononi 2010), as well as general models of cognition that emphasize network connectivity (e.g., McIntosh 2000).

This leads to the likelihood that the degree of network complexity of a species' brain is proportional to the complexity of their conceptual universe, or their understanding of the world.

6 Species Differences in Network Complexity

Given that concepts are in some fundamental way dependent on brain network activation states, comparisons of the neuroanatomical differences across species, in particular between humans and our closest ape relatives, suggest significant differences in their respective degrees of conceptual complexity. Differences in brain size are one obvious feature of potential relevance to network complexity, but there are a number of correlates of brain size that also suggest important ape/human differences in network complexity, and therefore in conceptual complexity.

The human brain is about three times the size of a chimpanzee brain, in absolute terms (Jerison 1973). Although it is true that brain size is correlated with body size across mammals, it is not clear that relative brain size (i.e., brain size corrected for body size) is a better marker of behavioral ability than is simply absolute brain size (Schoenemann 2006). Empirically, in fact, absolute brain size is a better predictor of general cognitive ability than is relative brain size, for primates at least (Deaner et al. 2007). For one thing, larger brains have greater numbers of neurons (Haug 1987, Herculano-Houzel 2012), leading to a greater total number of connections. Interestingly however, the connections do not increase at a rate fast enough to maintain the same degree of interconnectivity between regions (Ringo 1991). In other words, as brain size increases, neural processing in given areas becomes increasingly independent of the processing in other regions (though never completely so, of course). This leads to the increased likelihood of specialization of function of areas, simply as a consequence of increasing brain size. Empirically, the size of a species' brain predicts the number of anatomically distinct brain regions (which are assumed to be functionally distinct as well, Changizi & Shimojo 2005; Northcutt & Kaas 1995). Estimating from brain size, the number of distinct areas for humans is approximately 150, compared to the estimated number for apes of approximately 100 (Changizi & Shimojo 2005).[1] In addition, the number of connections between areas appears to increase as a function of the square of the total number of areas (Changizi & Shimojo 2005). Gibson (2002) has argued such

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[1] During production of this book, a new article was published arguing that the human brain actually has 180 distinct cortical areas (Glasser et al. 2016). This occurred too late to allow for recalculations of the estimates discussed in this chapter, but would in any case only magnify the expected human/chimp difference in conceptual complexity as proposed here.

evolutionary changes in our brain led to a significant increase in the ability to mix "actions, perceptions, and concepts" (p. 10), which she sees as important for language evolution.

To give a sense of what a difference in the number of distinct processing areas might mean for differences in degrees of conceptual complexity, assuming it is in some manner a function of degree of the number and types of network activation states, we can look at the increases in possible network activation states made possible by the additional 50 or so cortical areas in humans. First, consider that some concepts, such as individual colors, are likely the function of processing at single areas, rather than interactions among more than one area. The difference between human and ape complexity for concepts like this would be a function of the ratio of distinct cortical areas (using estimates derived from Changizi & Shimojo 2005), or 1.5 times (i.e., 150/100). In other words, everything else being equal, and assuming individual areas in the two species are equally complex in their internal processing (which is not necessarily likely – see later discussion), we would expect humans to have about 1.5 times as many of these basic concepts as do chimpanzees. We can think of this ratio as an estimate of possible increased network complexity, and therefore of possible increased conceptual complexity. Note that a ratio is probably a safer comparison for these purposes than is the absolute increase in numbers of areas, because our knowledge of how processing in individual areas is connected to specific concepts is limited. The use of a ratio for comparison just assumes the process of concept formation is essentially the same across species.

Not all concepts are likely the result of processing in single cortical areas, however. Several concepts likely rely on the interaction of at least two distinct areas. For example, our perception of flavor is actually a mix of olfactory (smell) and gustatory (taste) processing, though additional neural systems often contribute to our sensation of flavor as well (Shepherd 2006). To get a crude estimate of the possible complexity of conceptual awareness that could result from combinations of two different areas, we can calculate the possible combinations of sets of two areas given either 150 (human) or 100 (ape) total distinct areas.[2] The corresponding ratio of increased complexity in this case would be around 2.3x (11175/4950). This ratio continues to rise as we consider sets of 3, 4, 5, and so on combinations of these areas (Figure 4.1). If concepts for both species can be a function of as many as 11 distinct areas, this would

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[2] This is calculated in the following way: For a given number of areas assumed per concept, the number of possible combinations (ignoring the order) equals n!/[(k!)(n-k)!], where n = total number of individual areas, and k = number of areas allowed per combination. As one considers larger possible subset sizes, the total number of all possible combinations is the sum of combinations for each value of k up to and including the largest subset size of interest: [total number of possible combinations]=[combinations for k=1]+[combinations for k=2]+ ...[combinations for largest subset size].

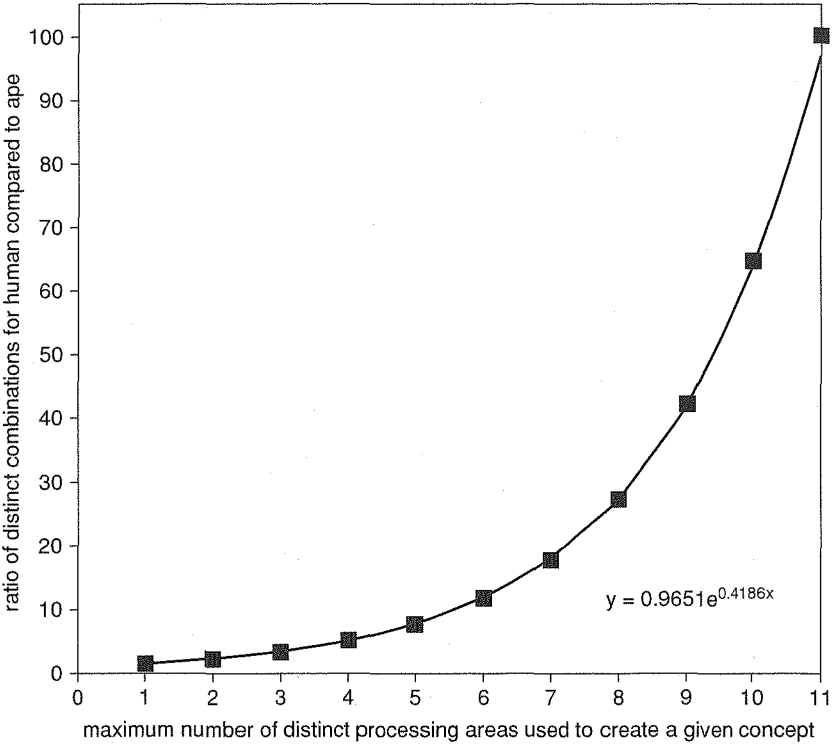

Figure 4.1 Increase in ratio of possible combinations of areas for human vs. ape. Figure 4.1 illustrates how many more combinations of areas there could be, in theory, for humans vs. apes, assuming humans have 150 distinct areas, and apes have only 100. The ratio advantage for human brains increases exponentially as the maximum numbers of areas possible per unique combination of areas is increased (*X*-axis). These are illustrations of possible differences given a simple model of concept formation, and are not estimates of actual ratios of conceptual complexity in humans vs. apes. See text for details and references.

translate to more than a 100-fold advantage for humans in number of theoretically possible concepts. Caution should be taken in assessing these calculations, of course, as they are based on a number of simplifying assumptions. For example, we don't know how the maximum number of different areas that could potentially contribute to a concept, so exactly how far out on the *X* axis of Figure 4.1 we should consider is not clear. It is also entirely possible that larger brains are actually better at integrating increasingly larger numbers of areas, and thus, that some human concepts might be formed from a larger number of areas than occurs in apes. This would mean that we should not be comparing equivalent cortical area set sizes between them, as Figure 4.1 assumes. However, note that this would *magnify* the probable difference in conceptual complexity between humans and apes. These calculations are not meant to be taken as definitive measures, but simply to highlight the possible effects of anatomical differences between humans and apes on conceptual complexity.

In addition to the increased *number* of cortical areas found in human compared to ape brains, individual areas themselves appear to be larger in humans. Calculating from Changizi and Shimojo's (2005) regressions of average percentage size of a neocortical area as a function of absolute brain size across mammals, one can calculate that human areas are on average approximately 2.3 times larger, in absolute terms, than what we would expect for corresponding areas in apes. There is substantial variation across particular regions, of course. The human primary visual cortex (V1, or Brodmann area 17) is only 1.6 times as large as that found in chimpanzees (data from Stephan et al. 1981), while Brodmann area 10 of the prefrontal is 6.3 times as large in absolute terms (data from Semendeferi et al. 2001).

Does this necessarily translate into increased complexity of processing? One reason to suspect it does comes from Penfield's (1950) pioneering work mapping the primary motor and somatosensory cortices. He found that there were substantial differences in the amount of cortex devoted to different areas of the body, with areas demonstrating greater sensitivity or degree of motor control having correspondingly larger cortical representations. He strikingly illustrated this with images in which body parts are drawn in proportion to the size of the cortical representation for each area. For example, the lips of these homunculi are very large, consistent with the fact that we have much greater sensitivity to our lips than to many other parts of our body. This indicates that the size of a cortical area does in fact have a functional consequence for primary motor and somatosensory areas within humans. Additionally, some studies have reported that the size of localized areas of the cortex correlate with degrees of ability for behaviors mediated by those areas (e.g., Schoenemann et al. 2000; Thompson et al. 2001). This all suggests that larger cortical areas do in fact correspond to more complex processing of information mediated by those areas in humans.

Across species there also appear to be associations between the proportion of cortex that mediates a particular behavior and the degree of elaboration of function of that behavior. For example, Star-nosed moles (*Condylura cristata*) that live most of their life underground and consequently have very poor eyesight have correspondingly small primary visual cortices, whereas ghost bats (*Macroderma gigas*) that depend heavily on echolocation devote about half their cortex to auditory processing (Krubitzer 1995). Thus, both across species and within humans, the size of a cortical area appears to be associated with the degree of function of that area (Schoenemann 2010).

All of this suggests not only that humans have a greater number of distinct cortical areas with more connections between areas, but also that individual areas are likely capable of more complex types of processing. This would further magnify the expected difference in complexity, subtlety, and richness of concepts in humans compared to apes – beyond what one might expect, based on differences in the number of distinct areas alone.

Finally, during human evolution there appears to have been a biased increase specifically in areas known to be relevant to language processing. For example, the temporal lobe, which is known to mediate connecting concepts to words (Damasio & Damasio 1992), is about 23 percent larger than expected, based on primate scaling trends (Rilling & Seligman 2002). In addition, other areas that participate in language processing, including prefrontal cortex, appear to have increased disproportionately during human evolution (see Schoenemann 2012 for a review).

All of this leads to the conclusion that there was a dramatic increase in conceptual complexity during our evolutionary lineage. Given that all of this increase occurred within the context of an intensely socially interactive group existence, it is hard to imagine that this increase in conceptual complexity was not fundamentally important to driving the evolution of language.

7 Conceptual Awareness in Other Species

The behavior of other species is consistent with the notion that they also have concepts, and further, that many of their concepts overlap in important ways with our own. However, an organism's conceptual understanding of the world will inevitably be influenced by the kinds of sensory information they have evolved to be aware of. Dogs do not have the same range of color information as humans do, but they appear to have better discrimination in low light and better differentiation of shades of grey (Miller & Murphy 1995; Neitz et al. 1989). Echolocating bats can hear frequencies far in excess of humans, and they can use echoes from these sounds to recreate spatial relationships between themselves and their flying insect prey (Jones & Holderied 2007). Elephants can produce and respond to sounds much lower than humans can hear (Garstang 2010). To the extent that species differ in their sensory awareness, their conceptual understanding of the world will likely be different.

There is, however, substantial overlap in the types of sensory information that humans have with other species, and the ways in which this information is categorized into conceptual information often appears to match that shown in humans. Experiments with categorization of images by pigeons, for example, suggest they organize visual information into categories corresponding essentially to PEOPLE and TREES that are very close to our own (Herrnstein 1979). Pigeons and monkeys have been shown to be able to correctly categorize still pictures of animals vs. non-animals, which is a fairly abstract concept (Roberts & Mazmanian 1988). Wasserman et al. (1988) found that pigeons learn to categorize images much faster if they are organized into sets that correspond to human language categories (e.g., CATS, FLOWERS, CARS and CHAIRS), as compared to arbitrary sets. This suggests that human languages and cultures make use of categories that are "real" to a wide variety of animals (Schoenemann 2005).

Monkeys appear to have several conceptual categories that correspond at least partly to those found for humans. Monkeys and apes are able to recognize faces of individuals in their groups (Parr 2011). Monkeys also act as if they understand complex social relationships, including hierarchical matrilineal kin groupings, not only with respect to their own positions but also that of others in their social group (Bergman et al. 2003; Seyfarth & Cheney 2000). Several species of monkeys and at least one small ape species (gibbon) have been shown to have different alarm calls for different predators (Clarke et al. 2006; Seyfarth et al. 1980; Zuberbuhler 2000).

In order for these primate species to have such calls, they must have separate concepts that relate differentially in some way to each type of predator (Schoenemann 2005). Cheney and Seyfarth (2005) argue these alarm calls are more properly thought of as propositions, as opposed to simple nouns identifying predators. Monkeys and apes (at least) do seem to have concepts that correspond to more than just THINGS. For example, individuals respond differently to others in their social group depending on the context. Apes have been reported to hug other individuals when they are distressed (de Waal 2008). Monkeys respond with reconciliatory behavior after an aggressive encounter with a dominant individual if that individual gives a specific kind of vocalization (Cheney & Seyfarth 1997). These kinds of behaviors show that they are sensitive to the *behaviors* displayed by others, which suggest that primates have conceptual understanding that differentiates ACTIONS from ACTORS (or THINGS). This is important part of the conceptual distinction marked by the VERBS VS. NOUNS in human language grammar.

The clearest evidence that apes have concepts comes from ape language studies, which have fairly convincingly shown that apes have the ability to use hand signs or lexicons to represent concepts of various kinds. Double-blind tests show that chimpanzees (*Pan troglodytes*) can correctly name objects with hand signs (Gardner & Gardner 1984; Gardner et al. 1989). Premack and Premack (1972) showed that chimpanzees could use lexigrams to answer questions about concepts related to objects. For example, when the subject Sarah was asked – via lexigrams – to name the color of "apple" (represented by a blue triangle in her sign system), she responded with the lexigram for "red." Perhaps the most extensive and impressive work so far with apes has been with Kanzi, a bonobo (*Pan paniscus*), by Savage-Rumbaugh and colleagues (Savage-Rumbaugh et al. 1993). In one study, Kanzi was presented with more than 660 novel and unusual sentences in controlled blind tests, including things like: "Pour the Coke in the lemonade," "Go get the can opener that's in the bedroom," and "Kanzi is going to chase Rose," and he responded correctly to 72 percent of these, which is far above chance given the complexity of the sentences. While there is controversy over the extent to which these show evidence of incipient *grammar* knowledge (e.g., Wynne 2008; but see Savage-Rumbaugh et al. 2009), Kanzi's understanding of a few hundred spoken English words – and by extension the concepts underlying them – is not seriously debated.

We can get some idea of the range of kinds of concepts that Kanzi appears to understand by looking more closely at the words in the sentences that he responded immediately and correctly to, as listed in Savage-Rumbaugh et al. (1993). Note that this leaves out cases where the researchers nevertheless believe Kanzi understood the sentence but responded imperfectly to it. For example, when Kanzi was told: "Put the carrot in the water," he picked up a carrot, made a vocalization, took a bite of the carrot, and then put it in the water. The researchers scored this "not immediately correct" because he ate some of the carrot beforehand (Savage-Rumbaugh et al. 1993: p. 162). Restricting our analysis only to sentences Kanzi immediately and correctly responds to also leaves out cases where he was only partially incorrect. For example, when instructed: "Give the big tomato to Liz," he picked up both the big and the little tomato and gave them to the researcher (Savage-Rumbaugh et al. 1993: p. 163). However, he didn't pick up any of the numerous other objects that are in front of him, and he didn't interact with any other researchers present, thereby suggesting that he only misunderstood a single word in the sentence, that is, "big," and not all the other words in the sentence. Restricting the analysis here just to those sentences to which Kanzi responded immediately and correctly is therefore highly conservative and strongly biased against overinterpreting Kanzi's understanding of spoken English. In the view of those who work with him, Kanzi almost certainly understands more than is indicated here.

In total, Kanzi responded correctly and immediately to 368 of the novel sentences in this study, involving a total of 2,354 word tokens. Parts of speech from these sentences were identified using tools from LingPipe, using the Brown corpus (Alias-i 2008), and then checked by visual inspection. Tables 4.1–4.5 list all the individual words in these sentences, divided into parts of speech categories, with the number of times each word appeared in the sentences also indicated. In total, there were 225 different words used across the sentences in this particular test. This included 119 nouns, 49 verbs, 32 adjectives/adverbs/prepositions, 11 pronouns, and the names of 14 different individuals. (Note that these counts collapse similar words into one instance, e.g., *hid*, *hide*, and *hiding*, are counted as one verb.) The fact that Kanzi responded correctly and immediately to all these sentences is of course not evidence that he necessarily understood every single one, or that he knows the concept ADVERB, for example.

Table 4.1 *Nouns Used in Sentences Kanzi Responded to Correctly*

Number of Occurrences	Nouns (119)
51	ball
32	outdoors
27	doggie
19	bedroom
18	refrigerator
17	water
16	room
14	rock
13	shot
12	microwave
12	oil
12	potty
11	milk, needles, snake, tomato, toothpaste
10	gorilla, pine, umbrella
9	TV
8	banana, orange, sparklers
7	bowl, collar, colony, juice, lighter, mask, raisins, stick, toy
6	backpack, bunny, can, carrot, melon, monster, mushrooms, opener, play, soap, vacuum
5	apple, cereal, ice, keys, rubber, yard, wipie(s)
4	band, blanket, clay, hat, hose, picture, pillow, potato, teeth, telephone
3	balloon, cabinet, coke, dog, door, hand, head, hotdogs, Jello, lemonade, money, paint, peas, phone, pineapple, shoe
2	book, cleaner, coffee, food, hotdog, knife, orang, paper, tickle
1	bananas, bands, bark, bottle, bubbles, butter, cane, car, clovers, diaper, egg, fire, flashlight, Fourtrax, grapes, hair, hammer, hug, lettuce, mouth, mushroom, onions, outside, oven, Perrier, potatoes, shirt, straw, sugar, surprise, tape, yogurt

However, Kanzi's performance on these sentences is strong evidence that, at a cognitive level, he not only understands that arbitrary sound patterns emanating from the researchers' lips can refer to specific concepts, but also that his underlying conceptual understanding is quite a bit broader than this vocal communication would otherwise suggest. His conceptual world appears not to be limited to individual items or people (nouns), but also includes concepts relating to ACTIONS (verbs), and even LOCATION (e.g., *on*, *with*) and temperature (*hot*). His performance on tasks like this depends on some non-trivial degree of shared conceptual understanding of the world, along with a deep desire to be a part of a social group in which communication between individuals is important.

Table 4.2 *Verbs Used in Sentences Kanzi Responded to Correctly*

Number of Occurrences	Verbs (49)
97	put
73	get
62	go/going
58	take
52	can
48	give
15	pour
13	show
12	open, tickle
11	is/are
8	bite
7	hid/hide/hiding
6	could, knife [cut with a knife], make, wash
5	brush, scare
4	chase, grab, see, slap/slapping
3	do, eat, hit, need, tell, throw, want
2	drink, gonna, groom, hug, keep, play, stab
1	bring, carry, close, feed, hammer, let, sit, squeeze, start, think, turn, would

While it is true that Kanzi and other ape language subjects are in highly unique circumstances (for non-human apes) and are not representative of what apes are doing in the wild, they do nevertheless allow us to understand what an ape brain is *capable* of, given the right sociocultural developmental circumstances. They are our best guess about what the cognitive capacities of our common ape ancestors would have been like. This research shows that animals, and in particular our closest primate relatives, have concepts and can use arbitrary signs to refer to these concepts in interesting and important ways.

Table 4.3 *Proper Names Used in Sentences Kanzi Responded to Correctly*

Number of Occurrences	Proper Names (14)
31	Rose
21	Kelly
17	Liz
16	Kanzi
6	Linda, Sue
4	Matata
3	Panbanisha
2	Karen, Panzee
1	Austin, Krista, Panban, Sherman

Table 4.4 *Pronouns Used in Sentences Kanzi Responded to Correctly*

Number of Occurrences	Pronouns (11)
63	you
45	your
15	me
14	it
5	I
3	her, him, them, we
1	my

8 The Human Elaboration of Conceptual Complexity

While the evidence outlined here suggests that other animals, and in particular apes, have concepts, they nevertheless appear to be limited in the diversity, subtlety and complexity of their conceptual understanding. In his review of ape language studies, Snowdon (1990) remarks:

> Although the abilities of Kanzi and his companions are remarkable and come very close to some of the capacities shown by young children, there still appear to be limitations. Bonobos [pygmy chimpanzees] and chimps *appear to be more limited in the topics that they find interesting to communicate about* (p. 222, italics added).

This intuitive assessment is consistent with simple numerical differences in the number of signs that apes appear to be capable of learning compared to the number of words that humans typically understand. The previous analysis of

Table 4.5 *Adjectives, Adverbs and Prepositions Used in Sentences Kanzi Responded to Correctly*

Number of Occurrences	Adjectives/Adverbs/Prepositions (32)
451	the
92	to
79	in
54	on
40	and
38	some
22	that, with
19	a
4	down, out
3	hot, now, of
2	away, big, by, for, this
1	an, at, back, good, hide, if, new, off, over, real, somewhere, sweet, there

the sentences that Kanzi immediately and correctly responded to, for example, suggests he broadly understands the meaning behind at least 225 different words. This is broadly similar to what other ape language studies have reported. For instance, the orangutan Chantek reportedly learned 127 different signs (Miles 1990).

By contrast, humans have a working vocabulary that is several orders of magnitude larger. Miller and Gildea (1991) estimate that the average high school student knows the meanings of about 40,000 dictionary entries, and that adding proper names would likely double this number. This suggests there is at least a 100-fold increase in the ability to use arbitrary signs to refer to underlying concepts in humans compared to apes.

However, to what extent should we expect these apparent differences in the sheer number of lexical items (or communicative signs) to actually reflect underlying differences in the richness, subtlety, and complexity of conceptual understanding, as opposed to simply reflecting a difference in the ease or ability of attaching arbitrary signs to the underlying conceptual meanings? It is true that Kanzi's use of signs for communicative purposes reportedly increased at a slower rate than is typical for normal human children (Savage-Rumbaugh & Rumbaugh 1993). However, both Kanzi and his half-sister Panbanisha continued to learn new words into adulthood, in a social context in which words were used by their caregivers (Lyn & Savage-Rumbaugh 2000). Slower learning of communicative signs in apes might reflect a difference in their ability to infer the possible meaning from a complex environment, rather than some specific difficulty associating signs with concepts. However, given the differences in brain anatomy outlined earlier, and their relevance to the possible richness of conceptual understanding, it is likely that a large part of the difference in number of signs for communication highlighted here does reflect a difference in underlying conceptual complexity.

To get a visual sense of the possible difference in complexity of the human semantic network compared to that for Kanzi, semantic similarities were calculated on the corpus of Kanzi's correct sentences (described earlier) and compared to those calculated on an adult human speech corpus: the Charlotte Narrative and Conversation Collection. This is a corpus of 95 narratives, conversations and interviews from residents of Mecklenburg County, North Carolina, and surrounding North Carolina communities, from the American National Corpus Consortium (www.americannationalcorpus.org). The relative semantic similarity between words was calculated using the BEAGLE method (*Bound Encoding of the Aggregate Language Environment*), which relies on statistical redundancies within a corpus to build a semantic space representation of meaning (Jones & Mewhort 2007). Because the human corpus used here contains around 8,700 words, a single figure depicting the estimated semantic network is too dense to assess; only a subset of the human network can be displayed. As a simple comparison, corresponding human/ape semantic networks were plotted connecting all words estimated by the BEAGLE method to be semantically closer to the word "milk" that is the word "oil." There were 16 such words in Kanzi's corpus (Figure 4.2(a), compared to 108 for the human corpus (Figure 4.2(b). As is immediately obvious, the semantic network for these broadly equivalent subsets are dramatically different in the two species, with the human network much richer and covering a much larger portion of possible semantic meaning space.

The density of the semantic space implied by these corpora, as estimated by the BEAGLE method, varies quite a bit in different areas, however. Table 4.6 illustrates the relative densities of the same areas of semantic space for Kanzi vs. humans. The numbers represent the total number of words estimated to be closer to the target word than is the comparison word for Kanzi's corpus and the human corpus. As can be seen from these examples, in some regions the semantic density seems to be much greater in the human corpus than the corresponding area in Kanzi's corpus (e.g., the space around the target word "apple"), but for the others listed the difference is smaller, and in one case even reversed (e.g., Kanzi's estimated semantic space has 25 words closer to "eat" than is "get," but for the human corpus "get" is the closest word to "eat").

This comparison is imperfect for a variety of reasons, and should only be seen as a suggestive first attempt at a numerical comparison of semantic richness between the species. Kanzi's corpus was taken from sentences specifically selected to assess his understanding of spoken English, and as such were thought to be sentences he had never encountered before. The human corpus represents a sample of spoken English, but obviously does not consist of sentences designed to test knowledge of spoken language. Nevertheless, Kanzi's corpus is one of the broadest that has been published for apes, and as such this comparison is the best look at species differences in richness of semantic meaning that is currently available. Future work exploring the semantic space between species will hopefully refine the comparisons, but this initial assessment is at least consistent with a dramatic difference in the degree of conceptual complexity, as is predicted by comparisons of brain structure and function between humans and apes.

Finally, note that the basic argument here is not inconsistent with Deacon's (1997; 2012) view that there is a fundamental qualitative difference between humans and all other animals in the types of signs we are able to use. Deacon relies on Peirce's (1867) taxonomy of types of signs, in which "icons" are signs that directly resemble their referents, "indexes" are signs that correlate reliably with their referents, and "symbols" are signs that refer to their referents only in non-iconic, non-indexical ways, such that they are completely arbitrary conventionalizations. Deacon believes that only humans and language-trained apes like Kanzi truly understand and use signs that are symbols in this sense, and for

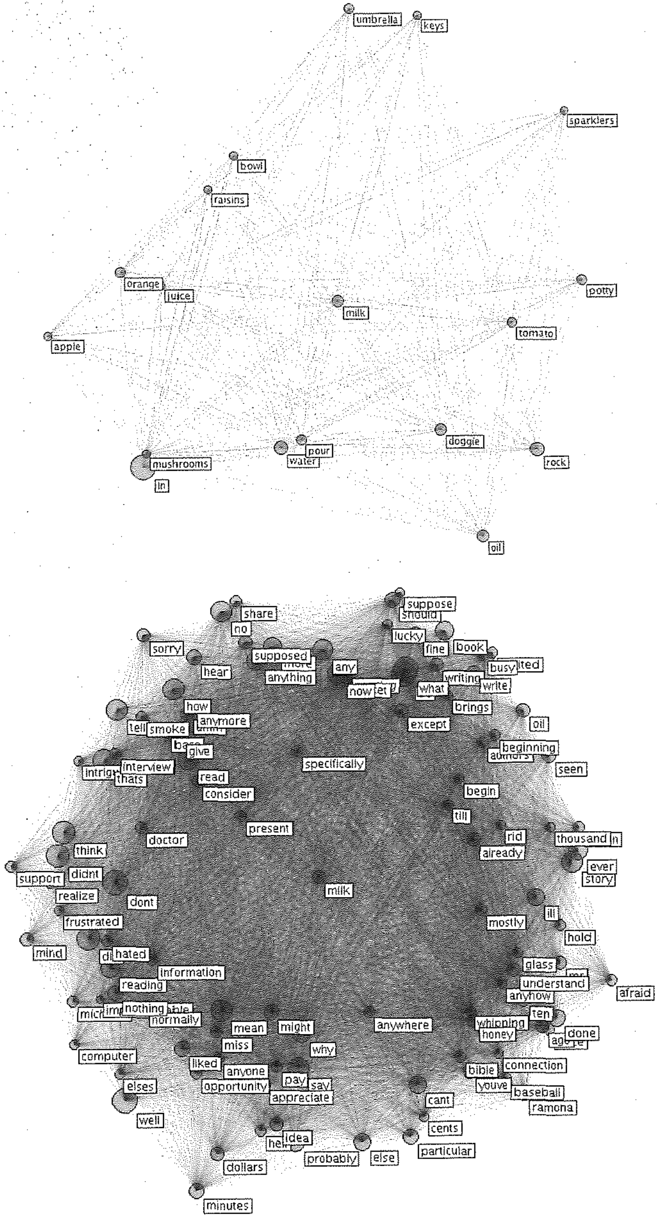

Figure 4.2 Comparison of semantic network density for ape vs. human corpora. These figures show a subset of the estimated semantic meaning space for: (a) Kanzi's corpus of sentences he responded to immediately and correctly, and (b) the Charlotte Narrative and Conversation Collection corpus (see text). These figures plot the meaning space that contains all the words estimated to be as close to, or closer than, "milk" is to "oil." There were 17 such words for Kanzi's corpus and 110 in the Charlotte Narrative and Conversation Collection corpus. Semantic meaning space was calculated using the BEAGLE method (see text). Lines between word nodes represent estimates

Table 4.6 *Comparative Semantic Web Density for Select Words in Human vs. Chimp*

	Number of Words Closer to Target Word than the Comparison Word for		
Target Word	Comparison Word	Human	Kanzi
apple	raisin(s)	6747	7
milk	paper	354	40
milk	oil	108	16
carrot	flashlight	267	120
eat	get	0	25

Numbers in the columns represent the total number of words estimated to be closer semantically to the target word than is the comparison word. Semantic network was estimated using the BEAGLE method. See text for details on the human and Kanzi corpora used for this analysis.

him this is the key difference. But because he agrees that apes can learn to use symbols in particular developmental circumstances, the transition to symbolic behavior is for him fundamentally a behavioral one. Deacon also argues that symbols are built up dynamically from indexical relationships (Deacon 2012). The more complex the underlying conceptual structure, the more potential there would likely be for symbolic behavior in Deacon's sense.

9 Emergence of Syntax

The evidence laid out here supports the contention that there is a large difference between humans and our closest relatives in the degree of underlying conceptual complexity. Considered in the context of primate interactive sociality, it is hard to believe this would not have had a fundamental influence in driving the evolution of language. As an enhanced communication system, the usefulness of language is partly a function of the usefulness of the underlying conceptual system it is used to convey. While some theorists have suggested that language should not be thought of as primarily a communication mechanism (e.g., Berwick et al. 2013), this is really just a reflection of these theorists' conflation of underlying conceptual structure (as viewed here) with a definition of language itself. A significant part of the underlying conceptual structure is almost surely pre-linguistic, and even pre-hominin. This is not to say that it is identical in non-human primates, but rather that it formed the basis for language (as a communication mechanism) in the first place. There would not have been any reason to evolve any kind of enhanced communication system (leading ultimately to language) *absent* the development of a rich underlying conceptual structure to begin with. What would be the point?

It is also sometimes claimed that monkeys have very limited communication systems (e.g., Berwick et al. 2013). Typically, what is actually meant by this is that they only have a few identifiable *vocal* calls. However, this ignores the tremendous subtlety of primate nonverbal communication (Suomi 1997) and, as a result, is vastly too simplistic a view of primate communication. The reason non-human primate *vocal* communication systems are so simple is likely that individual survival is not enhanced by extensive vocal communication beyond a few calls specific to their most dangerous predators, as well as the variety of calls that play important roles in social signaling. It is quite clear that primates have very rich understanding of social relationships (Cheney & Seyfarth 2005; de Waal 1982). Cheney and Seyfarth (2005) specifically argue that "upon hearing vocalizations, listeners acquire information about their social companions that is referential, discretely coded, hierarchically structured, rule-governed, and propositional" (p. 135). Given what Kanzi and other ape sign communication projects have demonstrated, it appears to be possible for much (if not most) of this rich underlying conceptual understanding to be coded into some more elaborate vocal communication system, given the right developmental environment, and if it were specifically adaptive to do so.

It seems likely therefore that at some point our conceptual system became complex enough that – in the context of an intensely socially interactive existence, and in the relaxation of strong selective pressures against overt signaling (i.e., because risk of predation became sufficiently reduced) – an enhanced, complicated communication system involving grammar and syntax would have been inevitable. This would not, however, have required the evolution of dedicated, innately specified grammar circuits. The complexity of the grammatical system can be seen as an emergent feature of this process (Savage-Rumbaugh & Rumbaugh 1993; Schoenemann 1999). But what evidence is there that human language grammar could actually result simply from increasing conceptual complexity? The details of how this might have happened have not been worked out in detail, but several additional areas of study point in this direction.

First, it should be noted that the claim of a clear distinction between grammar and underlying conceptual understanding has been disputed. Some linguists have specifically emphasized the fundamental interconnectedness of grammar and semantics (e.g., Haiman 1985; Langacker 1987; O'Grady 1987). To the extent that these alternative models of language are correct, we would expect increasing conceptual complexity to, in effect, essentially mean the same thing as increasing grammatical complexity. These models fit an evolutionary framework much more elegantly than do those from the formalist tradition.

Second, proposed substantive features of Universal Grammar actually look suspiciously like descriptions of how we conceptualize the world, rather than specific rules about how components of language are structured (Schoenemann 1999). For example, Pinker and Bloom (1990) produce a list of "uncontroversial facts about substantive universals, the building blocks of grammars that all theories of universal grammar posit…" (p. 713). One they list is: "Phrase structure rules (e.g., "X-bar theory" or "immediate dominance rules") force concatenation in the string to correspond to semantic connectedness in the underlying proposition, and thus provides linear clues of underlying structure…" (p. 713). This amounts to simply saying that all languages have rules about how to translate complex, multidimensional conceptual meaning to a linear string of sounds. What is *not* universal is a particular, specific set of rules that all languages adhere to. Instead, languages differ, sometimes substantially, in what these particular rules look like (which is why Pinker and Bloom are not able to list specific rules shared universally). What this substantive universal amounts to is simply that all languages have some way of coding complex, multidimensional internal conceptual meaning into a serial channel (usually an auditory signal) in a conventionalized way. However, this is exactly what one would expect to occur purely through cultural evolutionary processes alone, if the purpose of language is to communicate meaning between individuals who share a basic conceptual understanding of the world.

To take another example, Pinker and Bloom (1990) posit that in all languages "Verb affixes signal the temporal distribution of the event that the verb refers to (aspect) and the time of the event (tense)…" (p. 713). This amounts to saying that all languages have rules that help express when some action occurred (tense), and how it was/is occurring (aspect). If the function of language is to allow communication between individuals sharing the same underlying conceptual understanding, then given that humans share a similar conceptualization of the passage of time, and given that time is highly relevant to humans, one would specifically expect conventionalized rules to emerge through cultural evolutionary processes that would allow speakers to mark this important information for listeners.

Assuming one important function of language has been the communication of conceptual understanding, we should expect that the structure of this conceptual understanding would have molded the structure of the grammar. This would be true whether or not the original purpose of language was thinking (e.g., Berwick et al. 2013). Language clearly has been used for communication for a long time and therefore its structure would necessarily be expected to have been significantly molded by shared conceptual understanding among speakers.

What is lacking in arguments for the evolution of grammar from the formalist tradition (e.g., Jackendoff 2002; Pinker & Bloom 1990) is the demonstration that cultural evolutionary processes *cannot* account for the emergence of shared grammatical rules from a common foundation of shared conceptualizations across individuals played out in the context of individuals in a socially interactive existence trying to share information.

Third, empirical studies of human children learning language suggest the development of grammatical knowledge is not actually independent of the development of lexical knowledge. Bates and Goodman (1997) have shown that complexity of grammatical knowledge in children's speech production is tightly correlated with the development and complexity of their (non-grammatical) lexicon. If grammar were truly an independent system, it should show evidence of being highly decoupled in development, yet it does not. In fact, linguistic development in children has been argued to be essentially item-based: young children use language in a way that suggests they do not understand and use abstract grammatical categories correctly until they have learned the holistic meanings of many isolated phrases first: the "verb-island" hypothesis (Tomasello 2000; Tomasello 2003). For example, in an experimental setting, two-year-old children rarely used novel verbs transitively if they had only been introduced to them in intransitive sentences, and vice versa, even though they understood the holistic meanings of particular transitive and intransitive sentences (Tomasello & Brooks Patricia 1998). This is consistent with the view that children construct their grammatical knowledge by first learning the meanings of whole structures, and then deduce the grammatical rules later based on repeated patterns they experience over being exposed to many independent tokens. This is not consistent with the idea of abstract innate grammatical categories independent of meaning. If this were the case, once a child had knowledge of transitive and intransitive sentences of any kind, they should be able to use all verbs in both ways; yet they do not.

There remains debate in the field of language learning, however, about whether or not children could learn all of syntax without at least some of it in some sense being specifically built-in (e.g., Universal Grammar) independent of the lexicon. Gleitman and colleagues (Gleitman 1990; Gleitman & Gleitman 1997; Gleitman et al. 2005), for example, have argued that children make use of syntactic knowledge to help them learn the meanings of words through a process they call "syntactic bootstrapping." Although they believe that some non-trivial amount of syntactic knowledge is innate in children, this claim is of course logically independent of whether or not syntactic bootstrapping occurs. Such bootstrapping would be expected to occur even if syntactic structure is simply a reflection of underlying shared conceptual understanding. From an evolutionary perspective, it makes more sense to suppose that conceptual understanding has molded language syntax, rather than believing that syntax has an independent evolutionary origin.

Lidz, Gleitman and colleagues have published a number of experiments that they believe demonstrate that children have expectations about what syntax looks like that they could not have learned from input. Their studies have focused specifically on learning verb-argument structure (Lidz et al. 2003a; Lidz & Gleitman 2004a; Lidz & Gleitman 2004b) and anaphoric reference (Lidz et al. 2003b). However, an array of non-innatist criticisms have been offered for their findings, including questioning whether the studies actually demonstrate something about innate syntax rather than simply their understanding of word meanings (Tomasello 2004), whether structure is really absent from the linguistic input children are exposed to (Foraker et al. 2009; Regier & Gahl 2004), and whether simple pragmatic constraints would be sufficient (Goldberg 2004).

Whether or not some aspects of syntactic knowledge are specifically coded innately, there is broad general agreement among child language learning researchers that syntactic knowledge and lexical knowledge develop together in children. For example, Lidz et al. (2003a) state: "As is now well attested, the verbs of the exposure language are acquired in lockstep with acquisition of those features of the clause-level grammar having to do with the relation between a verb's semantic argument structure and its syntactic structure" (p. 152; see also Berwick et al. 2013). Thus, both major models of language learning in children agree that lexical and grammatical knowledge are fundamentally linked.

Of particular interest to the central thesis of this chapter, Bates and Goodman (1997) review empirical evidence that the development of expressive grammatical complexity appears to be an exponential function of the size of the lexicon, such that grammatical complexity increases very slowly up to a vocabulary of around 200 words, and then begins to accelerate beyond that (Bates & Goodman 1997). In fact, children in the tenth percentile of grammatical complexity for vocabulary sizes of between 200–300 averaged a grammatical complexity score of zero (Bates & Goodman 1997). Note that ape sign communication studies typically report that subjects know about this many signs. It is thus not uncommon for children with vocabulary sizes matching those claimed for apes to similarly also show limited evidence of grammar in their production. A study of Kanzi's productive communicative sequences (as opposed to his comprehension abilities) when he was five years old showed that they were mostly limited to two words, thus limiting the complexity that could be expected (Greenfield & Savage-Rumbaugh 1991). Even so, some simple patterns were evident. Furthermore, language comprehension also precedes language production in human children, which in turn precedes evidence of grammar usage (Bates & Goodman 1997). Thus, the fact that Kanzi's comprehension precedes his production, and that his use of grammatical structure in expressions is limited compared to his comprehension of grammatical structure (Greenfield & Savage-Rumbaugh 1991; Savage-Rumbaugh et al. 1993) is not a valid reason to suspect a qualitative difference between apes and humans with respect to language. All of this is consistent with the emergence of grammatical complexity from increasing underlying conceptual understanding.

Last, the possibility of a purely cultural evolutionary transition to grammatical structure as a consequence of expanding lexicon has also been explored in computer simulations. Such simulations necessarily make a number of simplifying assumptions, but they serve as important tests of proof-of-concept, which is particularly important in the case of evolutionary arguments because human intuitions about evolutionary dynamics are often incorrect. Computer simulations of language evolution have generally shown that a surprising degree of emergent structure can occur from cultural evolution alone (for a review, see Gong et al. 2014; Steels 2011). Using an iterated learning agent-based model, Smith et al. (2003) showed that compositionality in communication systems (a precondition of grammar where the meaning of an entire signal sequence is a function of the meanings of subparts of the sequence and their order in the sequence) occurs only when the meaning space that agents are trying to communicate *itself* exhibits structure. In other words, structure in the communication system emerges from structure in the underlying meaning space (equivalent to conceptual complexity as it is used here). Earlier agent-based simulations (Batali 1998; Goroll 1999) had reported emergent compositionality deriving entirely from cultural evolution, though the effects of the structure of the meaning space were not investigated (e.g., Batali 1998). More recently, Gong (2009; 2011) using an elegant model of interacting agents endowed only with general learning abilities, an ability to create signals of arbitrary type, and a simple interactive social environment, was able to simulate not only the emergence of compositionality but also consistent sequential order of lexical items, again, solely through cultural evolutionary mechanisms. Spranger and Steels (2012) further report the emergence of a communication system displaying incipient hierarchical structure and grammatical marking for spatial information in a simulation of robots playing a cooperative spatial identification guessing game. This occurred even though these features had not been built into the system to begin with.

Although no simulation studies have yet reported the emergence of anything approaching the complexity of natural language syntax, the exploration of the effects of increasing conceptual complexity on emergent syntax through cultural evolution has only begun. These initial results are very promising, and suggest a great deal is yet to be learned about the possibility of the evolutionary emergence of grammar from changes in the underlying conceptual system.

10 Conclusions

The model of language evolution presented here suggests that increasing complexity of the meaning space during human cognitive evolution drove the development of syntax and grammar through cultural evolutionary processes. Language complexity is seen as a result of the complexity of the conceptual world it evolved to map and communicate. This model is not only more parsimonious than those requiring separate, independent genetic evolutionary scenarios for both our conceptual system and our linguistic grammatical system, but is also specifically supported by research in a number of areas of study. Our understanding of human brain evolution, when placed in the context of how concepts are instantiated in brains, leads to the conclusion that there has likely been a dramatic increase in conceptual complexity during our evolutionary history. Apparent differences in primate cognition, deriving from both studies of animals in the wild as well as those of captive animals, suggest this is true as well. In particular, it is apparent that other animals (non-human primates in particular) have concepts that meaningfully overlap with some of our own. The difference appears to be one of degree, not of kind. The tight connection between the size of the lexicon and the degree of grammatical complexity in speech production in human children actually fits very well with the data from studies of ape sign communication. Furthermore, several (perhaps all?) universal features of grammar found in languages around the world can be seen as inevitable cultural-evolutionary conventions resulting from a common underlying conceptual system, rather than requiring independent language-grammar-specific genetic constraints. Computer agent-based simulations have begun to investigate possible ways in which this model could work. Future work stands to flesh out these ideas, and demonstrate their full power in explaining the evolution of language.

This process highlights language as a complex adaptive system (Beckner et al. 2009). Grammar evolved through cultural evolution, making use of pre-existing, non-linguistic general cognitive abilities, and was driven by increasing complexity of underlying conceptual understanding played out in the context of an intensely socially interactive existence. Each of the parts of this equation were (and continue to be) influenced by the others, in a complex interactive feedback system, thus forming a complex adaptive system. Increasing conceptual complexity was itself presumably driven by an increasingly complicated social and technological existence. As social lives got more complicated, leading to new emergent social patterns (such as elaborated kinship systems and social institutions), new forms of conceptual understanding of these emergent patterns followed. Similarly, new technologies created new conceptual understanding. Technological advances, in addition to simply adding conceptually new devices to be named, also changed the social dynamics themselves. Agriculture, for example, dramatically increased population density, which in turn had profound effects on human sociality. More recently, technology applied in the social domain (social media) appears to be in the process of further elaborating and redefining sociality in a variety of interesting ways.

The usefulness of language, and grammar in particular, was likely also central to these social and technological developments. Thus, language, conceived in the broadest sense, itself facilitated further increases in conceptual complexity. Grammar and conceptual understanding influenced each other's evolutionary trajectories synergistically. They adapted to each other.

Although the model outlined here is consistent with what we know about the evolution of brain structure and function, comparative studies of primate cognition, child language learning, and with theories about language itself, the details of how increasing conceptual complexity itself could have led to complexity of language grammar remains to be described in detail. No doubt part of the story involves understanding how grammar itself evolves (culturally), as this suggests ways in which grammar could have emerged in the first place (Bybee 1998). Further work on exactly how children form grammatical concepts from the constructions they hear, and how their conceptual understanding might guide this process, will also be critical. Additionally, if this model is correct, it must be possible to instantiate and probe its dynamics with agent-based computer models of language evolution. The model predicts that elaborating the underlying conceptual understanding of the agents should have profound effects on the grammatical systems that emerge from the simulations. Such simulations would not prove language evolution occurred exactly this way, but simply provide proof-of-concept, and allow for a better understanding of what is possible from this perspective.

Unraveling the mystery of language evolution is central to understanding the origin and development of our species. The goal should be to explain as much as possible using cultural evolutionary mechanisms, since this change will occur faster, and will therefore be favored at each evolutionary time-step, compared to biological adaptation (Christiansen & Chater 2008). Because shared conceptual understanding is the foundation that language communication is based on, recognizing the importance of evolutionary changes in this system, and how it would play out over evolutionary time in a socially interactive existence, is likely to be fundamentally important to the explanation. Taking seriously language evolution as a complex adaptive system, involving interactions among many components, is a critical first step.

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