



Cognitive Science 34 (2010) 1131–1157

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ISSN: 0364-0213 print / 1551-6709 online

DOI: 10.1111/j.1551-6709.2009.01049.x

Language Acquisition Meets Language Evolution

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Received 21 July 2008; received in revised form 26 November 2008; accepted 4 March 2009

Abstract

Recent research suggests that language evolution is a process of cultural change, in which linguistic structures are shaped through repeated cycles of learning and use by domain-general mechanisms. This paper draws out the implications of this viewpoint for understanding the problem of language acquisition, which is cast in a new, and much more tractable, form. In essence, the child faces a problem of induction, where the objective is to *coordinate* with others (C-induction), rather than to model the structure of the natural world (N-induction). We argue that, of the two, C-induction is dramatically easier. More broadly, we argue that understanding the acquisition of any cultural form, whether linguistic or otherwise, during development, requires considering the corresponding question of how that cultural form arose through processes of cultural evolution. This perspective helps resolve the “logical” problem of language acquisition and has far-reaching implications for evolutionary psychology.

Keywords: Biological adaptation; Cognitive development; Cultural evolution; Evolutionary psychology; Induction; Language acquisition; Language evolution; Natural selection; Universal grammar

1. Introduction

In typical circumstances, language changes too slowly to have any substantial effect on language acquisition. Vocabulary and minor pronunciation shifts aside, the linguistic environment is typically fairly stable during the period of primary linguistic development. Thus, researchers have treated language as, in essence, fixed, for the purposes of understanding language acquisition. Our argument, instead, attempts to throw light on the problem of language acquisition, by taking an evolutionary perspective, both concerning the biological evolution

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of putative innate domain-specific constraints, and more importantly, the cultural evolution of human linguistic communication. We argue that understanding how language changes over time provides important constraints on theories of language acquisition; and recasts, and substantially simplifies, the problem of induction relevant to language acquisition.

Our evolutionary perspective casts many apparently intractable problems of induction in a new light. When the child aims to learn an aspect of human culture (rather than an aspect of the natural world), the learning problem is dramatically simplified—because culture (including language) is the product of past learning from previous generations. Thus, in learning about the cultural world, we are learning to “follow in each other’s footsteps”—so that our wild guesses are likely to be right—because the right guess is the most popular guess by previous generations of learners. Hence, considerations from language *evolution* dramatically shift our understanding of the problem of language *acquisition*; and we suggest that an evolutionary perspective may also require rethinking theories of the acquisition of other aspects of culture. In particular, in the context of learning about culture, rather than constraints from the natural world, we suggest that a conventional nativist picture, stressing domain-specific, innately specified modules, cannot be sustained.

The structure of the paper is as follows. In the next section, *Language as shaped by the brain*, we describe the logical problem of language evolution that confronts traditional nativist approaches, which propose that the brain has been adapted to language. Instead, we argue that language evolution is better understood in terms of cultural evolution, in which language has been adapted to the brain. This perspective results in a radically different way of looking at induction in the context of cultural evolution. In *C-induction and N-induction*, we outline the fundamental difference between inductive problems in which we must learn to coordinate with one another (C-induction), and those in which we learn aspects of the noncultural, natural world (N-induction). Crucially, language acquisition is, on this account, a paradigm example of C-induction. *Implications for learning and adaptation* shows: (a) that C-learning is dramatically easier than N-induction; and (b) that while innate domain-specific modules may have arisen through biological adaption to deal with problems of N-induction, this is much less likely for C-induction. Thus, while Darwinian selection may have led to dedicated cognitive mechanisms for vision or motor control, it is highly implausible that narrowly domain-specific mechanisms could have evolved for language, music, mathematics, or morality. The next section, *The emergence of binding constraints*, provides a brief illustration of our arguments, using a key case study from language acquisition. Finally, in *Discussion and implications*, we draw parallels with related work in other aspects of human development and consider the implications of our arguments for evolutionary psychology.

2. Language as shaped by the brain

Before most children can count to 10 or stand on one leg with their eyes closed for more than 10 s, they are already quite competent users of their native language. It seems that whatever inductive guesses children make about how language works, they tend to get it

right—even when presented with noisy and incomplete input. It is therefore widely assumed that there must be a tight fit between the mechanisms that children employ when acquiring language and the way in which language is structured and used. One way of explaining this close relationship is to posit the existence of domain-specific brain mechanisms dedicated to language acquisition—a Universal Grammar (UG)—through which the linguistic input is funneled (e.g., Chomsky, 1965, 1980). Current conceptions of UG vary considerably in terms of what is genetically specified, ranging from a set of universal linguistic principles with associated parameters in Principles and Parameter Theory (e.g., Crain, Goro, & Thornton, 2006; Crain & Pietroski, 2006), to a language-specific “toolkit” that includes structural principles relating to phrase structure (X-bar theory), agreement, and case-marking in Simpler Syntax (Culicover & Jackendoff, 2005; Pinker & Jackendoff, 2009), to the intricate recursive machinery that implements Merge within the Minimalist Program (e.g., Boeckx, 2006; Chomsky, 1995). However, despite the important theoretical differences between current approaches to UG, they all share the central assumption that the core components of UG, whatever their form, are fundamentally arbitrary, from the standpoint of building a system for communication. Thus, the abstract properties of UG do not relate to communicative or pragmatic considerations, nor from limitations on the mechanisms involved in using or acquiring language, or any other functional sources. Indeed, it has been argued that many aspects of UG may even hinder communication (e.g., Chomsky, 2005; Lightfoot, 2000), further highlighting the nonfunctional nature of UG.

The UG framework has been challenged with regard to its ability to account for language acquisition (e.g., Bates & MacWhinney, 1987; Pullum & Scholz, 2002; Tomasello, 2003), the neural basis of language (e.g., Elman et al., 1996; Müller, 2009), and purely linguistic phenomena (e.g., Croft, 2001; Goldberg, 2006; O’Grady, 2005). Whatever the merits are of these challenges (c.f., e.g., Crain & Pietroski, 2001; Laurence & Margolis, 2001; Wexler, 2004; Yang, 2002), our focus here is on what may be an even more fundamental predicament for UG theories: *the logical problem of language evolution* (Botha, 1999; Christiansen & Chater, 2008; Roberts, Onnis, & Chater, 2005; Zuidema, 2003). We argue that there is no credible account of how a richly structured, domain-specific, innate UG could have evolved. Instead, we propose that the direction of causation needs to be reversed: the fit between the neural mechanisms supporting language and the structure of language itself is better explained in terms of how language has adapted to the human brain, rather than vice versa. This solution to the logical problem of language evolution, however, requires abandoning the notion of a domain-specific UG.

2.1. *The logical problem of language evolution*

As for any other biological structure, an evolutionary story for a putative UG can take one of two routes. One route is to assume that brain mechanisms specific to language acquisition have evolved over long periods of natural selection by analogy with the intricate adaptations for vision (e.g., Pinker & Bloom, 1990). The other rejects the idea that UG has arisen through adaptation and proposes that UG has emerged by nonadaptationist means (e.g., Bickerton, 1995; Gould, 1993; Jenkins, 2000; Lightfoot, 2000).

The nonadaptationist account can rapidly be put aside as an explanation for a domain-specific, richly structured UG. The nonadaptationist account boils down to the idea that some process of *chance variation* leads to the creation of UG. Yet the probability of randomly building a fully functioning, and completely novel, biological system by chance is infinitesimally small (Christiansen & Chater, 2008). To be sure, so-called evo-devo research in biology has shown how a single mutation can lead, via a cascade of genetic ramifications, to dramatic phylogenetic consequences (e.g., additional pairs of legs instead of antennae; Carroll, 2001). But such mechanisms cannot explain how a new, intricate, and functional system can arise *de novo*.¹

What of the adaptationist account? UG is intended to characterize a set of universal grammatical principles that hold across all languages; it is a central assumption that these principles are arbitrary. This implies that many combinations of arbitrary principles will be equally adaptive—as long as speakers adopt the *same* arbitrary principles. Pinker and Bloom (1990) draw an analogy between UG and protocols for communication between computers: It does not matter what specific settings are adopted, as long as every agent adopts the same settings. Yet the claim that a particular linguistic “protocol” can become genetically embedded through adaptation faces three fundamental difficulties (Christiansen & Chater, 2008).

The first problem stems from the dispersion of human populations. Each subpopulation would be expected to create highly divergent linguistic systems. But, if so, each population will develop a UG as an adaptation to a *different* linguistic environment—and hence, UGs should, like other adaptations, diverge to fit their local environment. Yet modern human populations do not seem to be selectively adapted to learn languages from their own language groups. Instead, every human appears, to a first approximation, equally ready to learn any of the world’s languages.² The second problem is that natural selection produces adaptations designed to fit the *specific* environment in which selection occurs, that is, a language with a specific syntax and phonology. It is thus puzzling that an adaptation for UG would have resulted in the genetic encoding of highly abstract grammatical properties, rather than fixing the superficial properties of one specific language. The third, and perhaps most fundamental, problem is that linguistic conventions change much more rapidly than genes do, thus creating a “moving target” for natural selection. Computational simulations have shown that even under conditions of relatively slow linguistic change, arbitrary principles do not become genetically fixed—this also applies when the genetic make-up of the learners is affecting the direction of linguistic change (Chater, Reali, & Christiansen, 2009; Christiansen, Chater, & Reali, in press).

Together, these arguments against adaptationist and nonadaptationist explanations of UG combine to suggest that there is no viable account of how such an innate domain-specific system for language could have evolved (for details, see Christiansen & Chater, 2008). It remains possible, though, that the origin of language did have a substantial impact on human genetic evolution. The above arguments only preclude biological adaptations for *arbitrary* features of language. There might have been features that are universally stable across linguistic environments that led to biological adaptations, such as the means of producing speech (e.g., Lieberman, 1984; but see also Hauser & Fitch, 2003), the need for enhanced memory capacity (Wynne & Coolidge, 2008), or complex pragmatic inferences (de Ruiter

& Levinson, 2008). However, these language features are likely to be functional—to facilitate language *use*—and thus would typically not be considered part of UG.

2.2. *Language as shaped by multiple constraints*

To escape the logical problem of language evolution, we need to invert the pattern of explanation underpinning the postulation of UG. Instead of viewing the brain as having a genetically specified, domain-specific system for language, which must somehow have arisen over the course of biological evolution, we see the key to language evolution to be evolutionary processes over language itself. Specifically, we view language as an evolving system, and the features of languages as having been shaped by repeated processes of acquisition and transmission across successive generations of language users (e.g., Christiansen, 1994; Culicover & Nowak, 2003; Deacon, 1997; Kirby & Hurford, 2002; Tomasello, 2003; for reviews, see Brighton, Smith, & Kirby, 2005; Christiansen & Chater, 2008). Aspects of language that are easy to learn and process, or are communicatively effective, tend to be retained and amplified; aspects of language which are difficult to learn or process, or which hinder communication, will, if they arise at all, rapidly be stamped out. Thus, the fit between the structure of language and the brains of language users comes about not because the brain has somehow evolved a genetically specified UG capturing the universal properties of language, but instead because language itself is shaped by the brain.

A key assumption of this evolutionary perspective is that language has been shaped by constraints from neural mechanisms that are not dedicated to language. But to what extent can such nonlinguistic constraints be identified and employed to explain linguistic structure previously ascribed to an innate UG? Christiansen and Chater (2008) identify four classes of constraint which simultaneously act to shape language.

2.2.1. *Perceptuo-motor factors*

The motor and perceptual machinery underpinning language seems inevitably to influence language structure. The seriality of vocal output, most obviously, forces a sequential construction of messages. A perceptual system with a limited capacity for storing sensory input forces a code that can be interpreted incrementally (rather than the many practical codes in communication engineering, in which information is stored in large blocks). The noisiness and variability (across contexts and speakers) of vocal or signed signals may, moreover, provide a pressure toward dividing the phonological space across dimensions related to the vocal apparatus and to “natural” perceptual boundaries (e.g., de Boer, 2000; Oller, 2000; Oudeyer, 2005)—though such subdivisions may differ considerably from language to language and thus do not form a finite universal phonological inventory (Evans & Levinson, 2008).

2.2.2. *Cognitive limitations on learning and processing*

Another source of constraints derives from the nature of cognitive architecture, including learning, processing, and memory. In particular, language processing involves extracting regularities from highly complex sequential input, pointing to a connection between

sequential learning and language: Both involve the extraction and further processing of discrete elements occurring in complex temporal sequences. It is therefore not surprising that sequential learning tasks have become an important experimental paradigm for studying language acquisition and processing (sometimes under the guise of “artificial grammar/language learning” or “statistical learning”; for reviews, see Gómez & Gerken, 2000; Saffran, 2003); and, indeed, some linguists have argued that some important cross-linguistic regularities arise from sequential processing constraints (e.g., Hawkins, 1994, 2004; Kirby, 1999).

2.2.3. *Constraints from thought*

The structure of mental representation and reasoning must, we suggest, have a fundamental impact on the nature of language. The structure of human concepts and categorization must strongly influence lexical semantics; the infinite range of possible thoughts presumably is likely to promote tendencies toward compositionality in natural language (Kirby, 2007); the mental representation of time is likely to have influenced linguistic systems of tense and aspect (Suddendorf & Corballis, 2007); and, more broadly, the properties of conceptual structure may profoundly and richly influence linguistic structure (Jackendoff, 2000). While the Whorfian hypothesis that language influences thought remains controversial, there can be little doubt that thought profoundly influences language.

2.2.4. *Pragmatic constraints*

Similarly, language is likely to be substantially shaped by the pragmatic constraints involved in linguistic communication. Pragmatic processes may, indeed, be crucial in understanding many aspects of linguistic structure, as well as the processes of language change. Levinson (2000) notes that “discourse” and syntactic anaphora have interesting parallels, which provide the starting point for a detailed theory of anaphora and binding. As we discuss further below, Levinson argues that initially pragmatic constraints may, over time, become “fossilized” in syntax, leading to some of the complex syntactic patterns described by binding theory. Thus, one of the paradigm cases for arbitrary UG constraints may derive, at least in part, from pragmatics.

Christiansen and Chater (2008) note that the four types of constraints interact with one another, such that specific linguistic patterns may arise from a combination of several different types of constraints. For example, the patterns of binding phenomena discussed below are likely to require explanations that cut across the four types of constraints, including constraints on cognitive processing (O’Grady, 2005) and pragmatics (Levinson, 1987; Reinhart, 1983). That is, the explanation of any given aspect of language is likely to require the inclusion of multiple overlapping constraints deriving from perceptuo-motor factors, from cognitive limitations on learning and processing, from the way our thought processes work, and from pragmatic sources.

The idea of explaining language structure and use through the interaction of multiple constraints has a long pedigree within functionalist approaches to the psychology of language (e.g., Bates & MacWhinney, 1979; Bever, 1970; Slobin, 1973). The integration of multiple

constraints—or “cues”—has risen to prominence in contemporary theories of language acquisition (see e.g., contributions in Golinkoff et al., 2000; Morgan & Demuth, 1996; Weissenborn & Höhle, 2001; for a review, see Monaghan & Christiansen, 2008). For example, 2nd-graders’ initial guesses about whether a novel word refers to an object or an action is affected by the sound properties of that word (Fitneva, Christiansen, & Monaghan, in press), 3-4-year-olds’ comprehension of relative clause constructions are affected by prior experience (Roth, 1984), 7-year-olds use visual context to constrain on-line sentence interpretation (Trueswell, Sekerina, Hill, & Logrip, 1999), and preschoolers’ language production and comprehension is constrained by perspective taking (Nadig & Sedivy, 2002). Similarly, many current theories of adult language processing also involve the satisfaction of multiple constraints (e.g., MacDonald, Pearlmutter, & Seidenberg, 1994; Tanenhaus & Trueswell, 1995), perhaps as a product of processes of language development driven by the integration of multiple cues to linguistic structure (e.g., Farmer, Christiansen, & Monaghan, 2006; Seidenberg & MacDonald, 2001; Snedeker & Trueswell, 2004).

We have considered some of the ways in which language is shaped by the brain. We now turn to the implications of this perspective on the induction problem that the child must solve in language acquisition.

3. C-induction and N-induction

Human development involves solving with two, inter-related, challenges: acquiring the ability to understand and manipulate the natural world (N-induction); and acquiring the ability to coordinate with each other (C-induction). Pure cases of these two types of problem are very different. In N-induction, the world imposes an external standard, against which performance is assessed. In C-induction, the standard is not external, but social: The key is that we do the *same* thing, not that we all do an objectively “right” thing. In reality, most challenges facing the child involve an intricate mixture of N- and C-induction—and teasing apart the elements of the problem that involve understanding the world, versus coordinating with others, may be very difficult. Nonetheless, we suggest that the distinction is crucially important, both in understanding development in general, and in understanding the acquisition of language, in particular.

To see why the distinction between N- and C-induction is important, consider the difference between learning the physical properties of the everyday world, and learning how to indicate agreement or disagreement using head movements. In order to interact effectively with the everyday world, the child needs to develop an understanding of persistent objects, exhibiting constancies of color and size, which move coherently, which have weight and momentum, and which have specific patterns of causal influences on other objects. The child’s perceptuo-motor interactions with the everyday world (e.g., catching a ball; Dienes & McLeod, 1993) depend crucially on such understanding; and do so individualistically—in the sense that success or failure is, to a first approximation, independent of how other children, or adults, understand the everyday world. The child is a lone scientist (Gopnik, Meltzoff, & Kuhl, 1999; Karmiloff-Smith & Inhelder, 1973).

By contrast, in C-learning, the aim is to do as others do. Thus, consider the problem of appropriately deploying a repertoire of head movements to indicate agreement. Whereas there are rich objective constraints, derived from physics, on catching a ball, the problem of communication via head movements is much less constrained—from an abstract point of view, several mappings between overt expressions and underlying mental states may be equivalent. For example, in Northern Europe nodding one’s head indicates “yes,” but in Greece nodding signals “no.” Similarly, in many places across the world, shaking one’s head is used for “no,” but in Sri Lanka it indicates general agreement (Wang & Li, 2007). What is crucial for the child is that it comes to adopt the *same* pattern of head movement to indicate agreement as those around it. The child is here not a lone scientist, but a musician whose objective is not to attain any absolute pitch, but to be “in tune” with the rest of the orchestra.

Before we turn to the question of why C-induction is dramatically easier than N-induction, note that the distinction between N- and C-induction is conceptually distinct from the debate between nativist and empiricist accounts of development (although it has striking implications for these accounts, as we shall see). Table 1 illustrates this point with a range of examples from animal behavior. Thus, in many species, innate constraints appear fundamental to solving N- and C-induction problems. Innate solutions concerning problems of N-induction include basic processes of flying, swimming, and catching prey, as well as highly elaborate and specific behaviors such as nest building. And such innate constraints are equally dominant in determining coordination between animals. Thus, for example, from a functional point of view, patterns of movement might translate into information about food sources in a range of ways; but genetic constraints specify that honey bees employ a *particular* dance (Dyer, 2002). This amounts to solving a problem of C-induction (although solving it over phylogenetic time, via natural selection, rather than solving it over ontogenetic time, via learning), because it is a problem of coordination: The bees must adopt the *same* dance with the same interpretation (and indeed dances do differ slightly between bee species). Courtship, rutting, and play behaviors may often have the same status—the “rules” of

Table 1

A tentative classification of a sample of problems of understanding and manipulating the world (N-induction) versus coordinating with others (C-induction) in nonhuman animals

	Innate Constraints Dominant	Learning Dominant
N-induction	Locomotion and perceptual-motor control (Alexander, 2003); hunting, foraging, and feeding (Stephens et al., 2007); nest building (Healy et al., 2008)	Learning own environment (Healy & Hurly, 2004), identifying kin (Holmes & Sherman, 1982), learned food preferences and aversion (Garcia et al., 1955)
C-induction	Insect social behavior (Wilson, 1971), fixed animal communication systems (Searcy & Nowicki, 2001), including the bee waggle dance (Dyer, 2002), many aspects of play (Bekoff & Byers, 1998), and mate choice (Anderson, 1994)	Social learning (Galef & Laland, 2005), including imitative song-birds (Marler & Slabbekoorn, 2004)

social interactions are genetically specified; but they are also somewhat arbitrary. The key is that these rules are coordinated across individuals—that a male courtship display is recognizable by relevant females, for example.

Equally, both N- and C-induction can be solved by learning. Animals learn about their immediate environment, where food is located, what is edible, and, in some cases, the identity of conspecifics—this is N-induction, concerning objective aspects of the world. Indeed, some learned behaviors (such as milk-bottle pecking in blue tits or food preparation techniques in chimpanzees or gorillas) may be learned from conspecifics, although whether by processes of emulation, imitation, or simpler mechanisms, is not clear (Hurley & Chater, 2005). To a modest degree, some nonhuman animals also learn to coordinate their behavior. For example, some song birds and whales learn their songs from others. Reproductive success depends on producing a “good” song defined in terms of the current dialect (Marler & Slabbekoorn, 2004), rather than achieving any “objective” standard of singing.

The distinction between problems of C- and N-induction is, then, conceptually separate from the question of whether an induction problem is solved over phylogenetic time, by natural selection (and specifically, by the adaptation of genetically encoded constraints), or over ontogenetic time, by learning. Nonetheless, the distinction has two striking implications for the theory of development, and, in particular, for language acquisition. First, as we shall argue, C-induction is dramatically easier than N-induction; and many aspects of language acquisition seem paradoxically difficult because a problem of C-induction is mischaracterized as a problem of N-induction. Second, the child’s ability to solve C-induction problems, including language acquisition, must primarily be based on cognitive and neural mechanisms *that predate the emergence of the cultural form to be learned*. That is, natural selection cannot lead to the creation of dedicated, domain-specific learning mechanisms for solving C-induction problems (e.g., innate modules for language acquisition). By contrast, such mechanisms may be extremely important for solving N-induction problems. Table 2,

Table 2

A tentative classification of sample problems of understanding and manipulating the world (N-induction) versus coordinating with others (C-induction) in human development

	Innate Constraints Dominant	Learning Dominant
N-induction	Low-level perception, motor control (Crowley & Katz, 1999), perhaps core naïve physics (Carey & Spelke, 1996)	Perceptual, motor, and spatial learning (Johnson, this issue, Newcombe, this issue; Shadmehr & Wise, 2005); science and technology (Cartwright, 1999)
C-induction	Understanding other minds (Tomasello et al., 2005), pragmatic interpretation (de Ruiter & Levinson, 2008), social aspects of the emotions (Frank, 1988), basic principles of cooperation, reciprocation, and punishment (Fehr & Gächter, 2002; Olson & Spelke, 2008)	Language, including syntax, phonology, word learning, and semantics (Smith, this issue), linguistic categorization (Sloutsky, this issue; Tenenbaum, this issue). Other aspects of culture (Geertz, 1973), including music, art, social conventions, ritual, religion, and moral codes

somewhat speculatively, considers examples from human cognition, including some of the topics considered in this special issue. Rather than focusing in detail on each of these cases, we focus here on the general distinction between N-induction and C-induction, before turning to our brief illustrative example, binding constraints.

4. Implications for learning and adaptation

Suppose that some natural process yields the sequence 1, 2, 3... How does it continue? Of course, we have far too little data to know. It might oscillate (1, 2, 3, 2, 1, 2, 3, 2, 1...), become “stuck” (1, 2, 3, 3, 3, 3...), exhibit a Fibonacci structure (1, 2, 3, 5, 8...), and any of an infinity of more or less plausible alternatives. This indeterminacy makes the problem of N-induction of structure from the natural world difficult, although not necessarily hopelessly so, in the light of recent developments in statistics and machine learning (Chater & Vitányi, 2007; Harman & Kulkarni, 2007; Li & Vitányi, 1997; Tenenbaum, Kemp, & Shafto, 2007).

But consider the parallel problem of C-learning—we need not guess the “true” continuation of the sequence. We only have to *coordinate* our predictions with those of other people in the community. This problem is very much easier. From a psychological point of view, the overwhelmingly natural continuation of the sequence is “...4, 5, 6...” That is, most people are likely to predict this. Thus, coordination emerges easily and unambiguously on a specific infinite sequence, even given a tiny amount of data.

Rapid convergence of human judgments, from small samples of data, is observed across many areas of cognition. For example, Feldman (1997) and Tenenbaum (1999) show that people converge on the same categories incredibly rapidly, given a very small number of perceptual examples; and rapid convergence from extremely limited data is presupposed in intelligence testing, where the majority of problems are highly indeterminate, but responses nonetheless converge on a single answer (e.g., Barlow, 1983). Moreover, when people are allowed to interact, they rapidly align their choice of lexical items and frames of reference, even when dealing with novel and highly ambiguous perceptual input (e.g., Clark & Wilkes-Gibbs, 1986; Pickering & Garrod, 2004). Finally, consider a striking, and important class of examples from game theory in economics. In a typical coordination game, two players simultaneously choose a response; if it is the same, they both receive a reward; otherwise, they do not. Even when given very large sets of options, people often converge in “one shot.” Thus, if asked to select time and meeting place in New York, Schelling (1960) found that people generated several highly frequent responses (so-called focal points) such as “twelve noon at Grand Central Station,” so that players might potentially meet successfully, despite choosing from an almost infinite set of options. The corresponding problem of N-induction (i.e., of guessing the time and place of an arbitrarily chosen event in New York) is clearly hopelessly indeterminate; but as a problem of C-induction, where each player aims to coordinate with the other, it is nonetheless readily solved.

C-induction is, then, vastly easier than N-induction—essentially because, in C-induction, human cognitive biases inevitably work in the learner’s favor as those biases are shared

with other people, with whom coordination is to be achieved. In N-induction, the aim is to predict Nature—and here, our cognitive biases will often be an unreliable guide.

Language acquisition is a paradigm example of C-induction. There is no human-independent “true” language, to which learners aspire. Rather, today’s language is the product of yesterday’s learners; and hence language acquisition requires *coordinating* with those learners. What is crucial is not *which* phonological, syntactic, or semantic regularities children prefer, when confronted with linguistic data; it is that they prefer the *same* linguistic regularities—each generation of learners needs only to follow in the footsteps of the last.

Note that the existence of very strong cognitive biases is evident across a wide range of learning problems—from categorization, to series completion, to coordinating a meeting. Thus, the mere existence of strong biases in no way provides evidence for a dedicated innate “module” embodying such biases. From this point of view, a key research question concerns the nature of the biases that influence language acquisition—these biases will help explain the structures that are, or are not, observed in the world’s languages. Moreover, the *stronger* the biases (e.g., flowing from the interaction of perceptuo-motor factors, cognitive limitations on learning and processing, and constraints from thought and pragmatics, as described above), the *greater* the constraints on the space of possible languages, and hence the *easier* the problem of language acquisition.

Language, and other cultural phenomena, can therefore be viewed as evolving systems, and one of the most powerful determinants of which linguistic or cultural patterns are invented, propagated, or stamped out, is how readily those patterns are learned and processed. Hence, the learnability of language, or other cultural structures, is not a puzzle demanding the presence of innate information, but rather an inevitable consequence of the process of the incremental construction of language, and culture more generally, by successive generations (Deacon, 1997; Kirby & Hurford, 2002; Zuidema, 2003).

The first implication we have drawn from the distinction between C-induction and N-induction is that C-induction is dramatically easier than N-induction. But there is a second important implication, concerning the feasibility of the biological adaptation of specific inductive biases—that is, whether genetically encoded domain-specific modules could have arisen through Darwinian selection. This possibility looks much more plausible for problems of N-induction than for C-induction.

Many aspects of the natural world are fairly stable. Thus, across long periods of evolutionary time, there is little change in the low-level statistical regularities in visual images (Field, 1987), in the geometric properties of optic flow, stereo, or structure-from-motion (Ullman, 1979), or in the coherence of external visual and auditory “objects” (e.g., Bregman, 1990). These aspects of the environment therefore provide a stable selectional pressure over which natural selection can operate—often over times scales of tens or hundreds of millions of years. Just as the sensory and motor apparatus are exquisitely adapted to deal with the challenges of the natural environment, so it is entirely plausible that the neural and cognitive machinery required to operate this apparatus is equally under genetic control, at least to some substantial degree (e.g., Crowley & Katz, 1999). Indeed, in many organisms, including many mammals, much complex perceptual-motor behavior is functioning within hours of birth. Perceptuo-motor function appears to be considerably

delayed in human infancy, but it is nonetheless entirely plausible that some innate neural structures are conserved, or perhaps even elaborated, in humans. More broadly, it is at least *prima facie* plausible that biases regarding many problems of N-induction might be established by natural selection.

Consider, by contrast, the case of C-induction. While the natural world is stable, the behaviors on which people coordinate are typically highly *unstable*. Thus, the choice of meeting place in New York will, clearly, depend on contingent historical and cultural factors; but more importantly, cultural and linguistic conventions are in general highly labile—for example, the entire Indo-European language group, including Armenian, Finnish, Hindi, Ukrainian, and Welsh, which exhibit huge variations in case systems, word order, and phonology, have diverged in just 10,000 years (Gray & Atkinson, 2003). Moreover, “focal points” on which people can converge may emerge very rapidly during an experiment; for example, different pairs of participants rapidly develop one of a wide range of classifications in a task involving novel tangrams (Clark & Wilkes-Gibbs, 1986), and complex patterns of conventions can arise very rapidly in the emergence of languages. For example, Nicaraguan sign language has emerged within three decades, created by deaf children with little exposure to established languages (Senghas, Kita, & Özyürek, 2004). Thus, from this perspective, Pinker and Bloom’s (1990) analogy between the evolution of vision and language breaks down because the former is primarily a problem of N-induction and the latter a problem of C-induction.

To summarize, C-induction involves learning what others will do; but what others will do is highly variable—and, crucially, changes far more rapidly than genetic change. Suppose that a particular set of cultural conventions is in play (a specific language, or religious or moral code). Learners with an inductive bias which, by chance, makes these conventions particularly easy to acquire will be favored. But there is no opportunity for those innate biases to spread through the population, because long before substantial natural selection can occur, those conventions will no longer apply, and a bias to adopt them will, if anything, be likely to be a disadvantage (Chater et al., 2009; Christiansen et al., in press). Hence, Darwinian selection will favor agents that are generalists—that is, can adapt to the changing cultural environment. It will, in particular, not involve the *coevolution* of genes and specific, though initially arbitrary, cultural conventions. Rapid cultural evolution (e.g., fast-changing linguistic, moral, or social systems) will automatically lead to a fit between culture and learners—because cultural patterns can only be created and propagated if they are easy to learn and use. But cultural evolution will work *against* biological (co)evolution in the case of malleable aspects of culture—rapid cultural change leads to a fast-changing cultural environment, which serves as a “moving target” to which biological adaptation cannot occur (c.f., Ance, 1999).

There has, indeed, been extensive computational and mathematical analysis of the process of cultural evolution, including some models of language change (e.g., Batali, 1998; Hare & Elman, 1995; Kirby, Dowman, & Griffiths, 2007; Nettle, 1999; Niyogi, 2006; Nowak, Komarova, & Niyogi, 2001; Richerson & Boyd, 2005). Learning or processing constraints on learners provide one source of constraint on how such cultural evolution proceeds. Under some restricted conditions, learning biases specify a “fixed” probability

distribution of linguistic/cultural forms, which from cultural evolution can be viewed as sampling (Griffiths & Kalish, 2005). In the general case, though, historical factors can also be crucially important—once a culture/language has evolved in a particular direction, there may be no way to reverse the process. This observation seems reasonable in the light of numerous one-directional “clines” observed in empirical studies of language change (Comrie, 1989).

While arbitrary conventions, in language or other aspects of culture, typically change rapidly, and hence do not provide a stable target upon which biological evolution can operate, there may be important aspects of language and culture that are *not* arbitrary—that is, for which certain properties have functional advantages. For example, the functional pressure for communicative efficiency might explain why frequent words tend to be short (Zipf, 1949), and the functional pressure to successfully engage in repeated social interactions may explain the tendency to show reciprocal altruism (Trivers, 1971). Such aspects of culture could potentially provide a stable environment against which biological selection might take place. Moreover, “generalist” genes for dealing with a fast-changing cultural environment may also be selected for. Thus, it is in principle possible that the human vocal apparatus, memory capacity, and perhaps the human auditory system, might have developed specific adaptations in response to the challenges of producing and understanding speech, although the evidence that this actually occurred is controversial (e.g., Lieberman, 1984; but see also Hauser & Fitch, 2003). But genes encoding aspects of culture that were initially freely varying, and not held constant by functional pressure, could not have arisen through biological evolution (Chater et al., 2009).

While the issues discussed above apply across cognitive domains, we illustrate the payoff of this standpoint by considering a particularly central aspect of language—binding constraints—which has been viewed as especially problematic for nonnativist approaches to language acquisition, and to provide strong grounds for the postulation of innate language-specific knowledge.

5. The emergence of binding constraints

The problem of binding, especially between reflexive and nonreflexive pronouns and noun phrases, has for a long time been a theoretically central topic in generative linguistics (Chomsky, 1981); and the principles of binding appear both complex and arbitrary. Binding theory is thus a paradigm case of the type of information that has been proposed to be part of an innate UG (e.g., Crain & Lillo-Martin, 1999; Reuland, 2008), and it provides a challenge for theorists who do not assume UG. As we illustrate, however, there is a range of alternative approaches that provide a promising starting point for understanding binding as arising from domain-general factors. If such approaches can make substantial in-roads into the explanation of key binding principles, then the assumption that binding constraints are arbitrary language universals and must arise from an innate UG is undermined. Indeed, according to the latter explanation, apparent links between syntactic binding principles and pragmatic factors must presumably be viewed as mere coincidences—rather than as

originating from the ‘‘fossilization’’ of pragmatic principles into syntactic patterns by processes such as grammaticalization (Hopper & Traugott, 1993).

The principles of binding capture patterns of use of, among other things, reflexive pronouns (e.g., *himself*, *themselves*) and accusative pronouns (e.g., *him*, *them*). Consider the following examples, where subscripts indicate co-reference and asterisks indicate ungrammaticality:

- (1) That John_i enjoyed himself_i/*him_i; amazed him_i/*himself_i.
- (2) John_i saw himself_i/*him_i/*John_i.
- (3) *He_i/he_j said John_i won.

Why is it possible for the first, but not the second, pronoun to be reflexive, in (1)? According to generative grammar, the key concept here is *binding*. Roughly, a noun phrase *binds* a pronoun if it c-commands that pronoun, and they are co-referring. In an analogy between linguistic and family trees, an element c-commands its siblings and all their descendents. A noun phrase, NP, *A*-binds a pronoun if it binds it; and, roughly, if the NP is in either subject or object position. Now we can state simplified versions of Chomsky’s (1981) three binding principles:

Principle A. Reflexives must be A-bound by an NP.

Principle B. Pronouns must not be A-bound by an NP.

Principle C. Full NPs must not be A-bound.

Informally, Principle A says that a reflexive pronoun (e.g., *herself*) must be used, if co-referring to a ‘‘structurally nearby’’ item (defined by c-command), in subject or object position. Principle B says that a nonreflexive pronoun (e.g., *her*) must be used otherwise. These principles explain the pattern in (1) and (2). Principle C rules out co-reference such as (3). *John* cannot be bound to *he*. For the same reason, *John likes John*, or *the man likes John* do not allow co-reference between subject and object.

Need the apparently complex and arbitrary principles of binding theory be part of the child’s innate UG? Or can these constraints be explained as a product of more basic perceptual, cognitive, or communicative constraints? One suggestion, due to O’Grady (2005), considers the possibility that binding constraints may in part emerge from processing constraints (see Section 2.2.2). Specifically, he suggests that the language processing system seeks to resolve linguistic dependencies (e.g., between verbs and their arguments) at the first opportunity—a tendency that might not be specific to syntax, but which might be an instance of a general cognitive tendency to resolve ambiguities rapidly in linguistic (Clark, 1975) and perceptual input (Pomerantz & Kubovy, 1986). The use of a reflexive is assumed to signal that the pronoun co-refers with an available NP, given a local dependency structure.

Thus, in parsing (1), the processor reaches *That John enjoyed himself...* and makes the first available dependency relationship between *enjoyed*, *John*, and *himself*. The use of the reflexive, *himself*, signals that co-reference with the available NP, *John*, is intended (c.f., Principle A). With the dependencies now resolved, the internal structure of the resulting clause is ‘‘closed off’’ and the parser moves on: [*That [John enjoyed himself]*] *surprised him*/**himself*. The latter *himself* is not possible because there is no appropriate NP available

to connect with (the only NP is [*that John enjoyed himself*]) which is used as an argument of *surprised*, but which clearly cannot co-refer with the *himself*. But in *John enjoyed himself*, *John* is available as an NP when *himself* is encountered.

By contrast, plain pronouns, such as *him*, are used in roughly complementary distribution to reflexive pronouns (c.f., Principle B). It has been argued that this complementarity arises pragmatically (Levinson, 1987; Reinhart, 1983); that is, given that the use of reflexives is highly restrictive, they are, where appropriate, more informative. Hence, by not using them, the speaker signals that the co-reference is not appropriate.³ Thus, we can draw on the additional influence of *pragmatic* constraints (Section 2.2.4).

Finally, simple cases of Principle C can be explained by similar pragmatic arguments. Using *John sees John* (see [2] above), where the object can, in principle, refer to any individual named John, would be pragmatically infelicitous if co-reference were intended—because the speaker should instead have chosen the more informative *himself* in object position. O’Grady (2005) and Reinhart (1983) consider more complex cases related to Principle C, in terms of a processing bias toward so-called upward feature-passing, though we do not consider this here.

The linguistic phenomena involved in binding are extremely complex and not fully captured by *any* theoretical account (indeed, the minimalist program [Chomsky, 1995]; has no direct account of binding but relies on the hope that the principles and parameters framework, in which binding phenomena have been described, can eventually be reconstructed from a minimalist point of view). We do not aim here to argue for any specific account of binding phenomena; but rather to indicate that many aspects of binding may arise from general processing or pragmatic constraints—such apparent relations to processing and pragmatics are, presumably, viewed as entirely coincidence according to a classical account in which binding constraints are communicatively arbitrary and expressions of an innate UG. Note, in particular, that it is quite possible that the complexity of the binding constraints arises from the interaction of *multiple* constraints. For example, Culicover and Jackendoff (2005) have recently argued that many aspects of binding may be semantic in origin. Thus, *John painted a portrait of himself* is presumed to be justified due to semantic principles concerning representation (the portrait is a representation of John), rather than any syntactic factors. Indeed, note too that, we can say: *Looking up, Tiger was delighted to see himself at the top of the leaderboard* where the reflexive refers to the name ‘‘Tiger,’’ not Tiger himself. And violations appear to go beyond mere representation—for example, *After a wild tee-shot, Ernie found himself in a deep bunker*, where the reflexive here refers to *his golfball*. More complex cases, involving pronouns and reflexives are also natural in this type of context, for example, *Despite Tiger_i’s mis-cued drive, Angel_j still found himself_(j’s golfball) 10 yards behind him_(i’s golfball)*. There can, of course, be no purely syntactic rules connecting golfers and their golfballs; and presumably no general semantic rules either, unless such rules are presumed to be sensitive to the rules of golf (among other things, that each player has exactly one ball). Rather, the reference of reflexives appears to be determined by pragmatics and general knowledge—for example, we know from context that a golfball is being referred to; that golfballs and players stand in one-to-one correspondence; and hence that picking out an individual could be used to signal the corresponding golfball.

The very multiplicity of constraints involved in the shaping of language structure, which arises naturally from the present account, may be one reason why binding is so difficult to characterize in traditional linguistic theory. But these constraints do not pose any challenges for the child—because these constraints are the very constraints with which the child is equipped. If learning the binding constraints were a problem of N-induction (e.g., if the linguistic patterns were drawn from the language of intelligent aliens; or deliberately created as a challenging abstract puzzle), then learning would be extraordinarily hard. But it is not: it is a problem of C-induction. To the extent that binding can be understood as emerging from a complex of processing, pragmatic, or other constraints operating on past generations of learners, then binding will be readily learned by the new generations of learners, who will necessarily embody those very constraints.

It might be argued that if binding constraints arise from the interaction of a multiplicity of constraints, one might expect that binding principles across historically unrelated languages would show strong family resemblances (as they would, in essence, be products of cultural *co-evolution*), rather than being strictly identical, as is implicit in the claim that binding principles are universal across human languages. Yet it turns out that the binding constraints, like other putatively “strict” language universals, may not be universal at all, when a suitably broad range of languages is considered (e.g., Evans & Levinson, 2008). Thus, Levinson (2000) notes that, even in Old English, the equivalent of *He saw him* can optionally allow coreference (apparently violating Principle A). Putative counterexamples to binding constraints, including the semantic/pragmatic cases outlined above, can potentially be fended off, by introducing further theoretical distinctions—but such moves run the real risk of stripping the claim of universality of real empirical bite (Evans & Levinson, 2008). If we take cross-linguistic data at face value, the pattern of data seems, if anything, more compatible with the present account, according to which binding phenomena results from the operation of multiple constraints during the cultural evolution of language, than the classical assumption that binding constraints are a rigid part of a fixed UG, ultimately rooted in biology.

To sum up: Binding has been seen as paradigmatically arbitrary and specific to language; and the learnability of binding constraints has been viewed as requiring a language-specific UG. If the problem of language learning were a matter of N-induction—that is, if the binding constraints were merely a human-independent aspect of the natural world—then this viewpoint would potentially be persuasive. But language learning is a problem of C-induction—people have to learn the *same* linguistic system as each other. Hence, the patterns of linguistic structure will themselves have adapted, through processes of cultural evolution, to be easy to learn and process—or more broadly, to fit with the multiple perceptual, cognitive, and communicative constraints governing the adaptation of language. From this perspective, binding is, in part, determined by innate constraints—but those constraints predate the emergence of language (de Ruiter & Levinson, 2008).

In the domain of binding, as elsewhere in linguistics, this type of cultural evolutionary story is, of course, incomplete—though to no greater degree, arguably, than is typical in genetic evolutionary explanations in the biological sciences. We suggest that viewing language as a cultural adaptation provides, though, a powerful and fruitful framework within

which to explore the evolution of linguistic structure and its consequences for language acquisition.

6. Discussion and implications

The theme of this special issue concerns one of the fundamental questions in cognitive development: the degree to which development is driven by domain-general learning mechanisms or by innate domain-specific constraints. The papers herein illustrate a variety of key developments in approaches that stress the importance of domain-general mechanisms, in areas ranging from conceptual development, to spatial cognition, to language acquisition. Here, our narrow focus has been on language. But our argument involved stepping back from questions concerning the acquisition of language, to take an evolutionary perspective, both concerning the biological evolution of putative innate constraints and the cultural evolution of human linguistic communication. Based on an evolutionary analysis, we proposed reconsidering development in terms of two types of inductive problems: N-induction, where the problem involves learning some aspect of the natural world, and C-induction, where the key to solving the learning problem is to coordinate with others. In this light, we then briefly reevaluated a key puzzle for language acquisition—the emergence of binding constraints—which has traditionally been interpreted as providing strong support for the existence of an innate UG. In this final discussion, we point to some of the broader implications of our approach for language acquisition and human development.

6.1. *The logical problem of language acquisition reconsidered*

We have argued that viewing the evolution of language as the outcome of cultural, rather than biological evolution (and hence as a problem of C-induction, rather than N-induction) leads to a dramatically different perspective on language acquisition. The ability to develop complex language from what appears to be such poor input has traditionally led many to speak of the “logical” problem of language acquisition (e.g., Baker & McCarthy, 1981; Hornstein & Lightfoot, 1981). One solution to the problem is to assume that learners have some sort of biological headstart in language acquisition—that their learning apparatus is precisely meshed with the structure of natural language. This viewpoint is, of course, consistent with theories according to which there is a genetically specified language module, language organ, or language instinct (e.g., Chomsky, 1986; Crain, 1991; Piattelli-Palmarini, 1989; Pinker, 1994; Pinker & Bloom, 1990). But if we view language acquisition as a problem of C-induction, then the learner’s objective is merely to follow prior learners—and hence the patterns in language will inevitably be those that are most readily learnable. It is not that people have evolved to learn language; rather, language has evolved to fit the multiple constraints of human learning and processing abilities.

Whatever learning biases people have, so long as these biases are *shared* across individuals, learning should proceed successfully. Moreover, the viewpoint that children learn language using general-purpose cognitive mechanisms, rather than language-specific mechanisms, has also been advocated on independent grounds (e.g., Bates & MacWhinney, 1979, 1987; Deacon, 1997; Elman et al., 1996; Monaghan & Christiansen, 2008; Seidenberg & MacDonald, 2001; Tomasello, 2000, 2003).

This alternative characterization of language acquisition additionally offers a different perspective on linguistic phenomena that have typically been seen as requiring a UG account for their explanation, such as specific language impairment (SLI) and creolization. These phenomena are beyond the scope of this paper, so we can only sketch how they may be approached. For example, the acquisition problems in SLI may, on our account, be largely due to deficits in underlying sequential learning mechanisms that support language (see Ullman & Pierpont, 2005; for a similar perspective), rather than impaired language-specific modules (e.g., Gopnik & Crago, 1991; Pinker, 1994; Van der Lely & Battell, 2003). Consistent with this perspective, recent studies have shown that children and adults with SLI have impaired sequential learning abilities (e.g., Evans & Saffran, 2005; Hsu, Christiansen, Tomblin, Zhang, & Gómez, 2006; Tomblin, Mainela-Arnold, & Zhang, 2007). Although processes of creolization, in which children acquire consistent linguistic structure from noisy and inconsistent input, have been seen as evidence of UG (e.g., Bickerton, 1984), we suggest that creolization may be better construed as arising from cognitive constraints on learning and processing. The rapid emergence of a consistent subject-object-verb word order in the Al-Sayyid Bedouin Sign Language (Sandler, Meir, Padden, & Aronoff, 2005) is consistent with this suggestion. Additional research is required to flesh out these accounts in detail, but a growing bulk of work indicates that such accounts are indeed viable (e.g., Chater & Vitányi, 2007; Goldberg, 2006; Hudson Kam & Newport, 2005; O'Grady, 2005; Reali & Christiansen, 2005; Tomasello, 2003).

6.2. *Cultural evolution meets evolutionary psychology*

How far do these arguments generalize from language acquisition to the development of the child's knowledge of culture more broadly? How far might this lead to a new perspective in evolutionary psychology, in which the fit between the brain and cultural forms is not explained in terms of domain-specific modules, but by the shaping of cultural forms to pre-existing biological machinery?

Human development involves the transmission of an incredibly elaborate culture from one generation to the next. Children acquire language; lay theories and concepts about the natural, artificial, and psychological worlds; social and moral norms; a panoply of practical lore and skills; and modes of expression, including music, art, and dance. The absorption of this information is all the more remarkable given that so much of it appears to be acquired incidentally, rather than being a topic of direct instruction.

As with language, it is *prima facie* unclear how this astonishing feat of learning is accomplished. One natural line of explanation is to assume that there is a close fit between the cultural information to be transmitted and the prior assumptions of the child,

whether implicit or explicit. The strongest form of this position is that some, and perhaps the most central, elements of this information are actually innately “built in” to each learner—and hence that cultural transmission is built over a skeleton of genetically fixed constraints (e.g., Hauser, 2006). Generalizing from the case of UG, some evolutionary psychologists have likened the mind to a Swiss army knife, consisting of a variety of special-purpose tools (Barkow, Cosmides, & Tooby, 1992). The design of each of these special-purpose tools is presumed to have arisen through biological selection. More broadly, the key suggestion is that there is a close mesh between genes and culture—and that this mesh helps explain how cultural complexity can successfully be transmitted from generation to generation.

The processes by which any putative connection between genes and culture might arise are central to the study of human development; and understanding such processes is part of the wider project of elucidating the relationship between biological and cultural explanation in psychology, anthropology, and throughout the neural and social sciences. But here we wish to take a wider view of these familiar issues, from the point of view of historical *origins*: How did the mesh between genes and culture arise?

The origin of a close mutual relationship between any two systems raises the question: Which came first? A natural line, in considering this type of problem, is to consider the possibility of co-evolution—and hence that the claim that one, or the other, must come first is misleading. As we have argued, in the case of genes and language, the conditions under which such co-evolution can occur are surprisingly limited; but the same issues arise in relation to the putative co-evolution of genes and any cultural form. Let us now broaden the argument and consider the two clear-cut options: that culture comes first, and biological adaptation brings about the fit with cultural structure; or the biological structures come first, and cultural adaptation brings about the fit with these biological structures. As a short hand, let us call these the *biological evolution* and *cultural evolution* perspectives.

How might biological evolution work? If cultural conventions have a particular form, then people within that culture will, we may reasonably assume, have a selective advantage if they are able to acquire those conventions rapidly and easily. So, for example, suppose that human cultures typically (or even always) fit some specific moral, social, or communicative pattern. Hence, children who are able rapidly to learn these constraints will presumably have a selective advantage. Thus, it is possible that, after a sufficiently long period of biological adaptation to an environment containing such constraints, learners who are genetically biased in favor of those constraints might emerge, so that they learn these constraints from very little cultural input; and, at the extreme, learners might be so strongly biased that they require no cultural input at all.⁴

If, though, we assume that genetic (or more generally biological) structure is *developmentally* prior (i.e., that learners acquire their culture via domain-specific genetic constraints, adapted to cultural patterns), then it appears that culture must be *historically* prior. The cultural structure (e.g., the pattern of specific syntactic regularities) provides the key aspect of the environment to which genes have adapted. Thus, if a genetically specified and domain-specific system containing specific cultural knowledge has arisen through Darwinian

processes of selection, then such selection appears to require a preexisting cultural environment, to which biological adaptation occurs. However, this conclusion is in direct contradiction to the key assumption of the biological approach—because it presupposes that the cultural forms do *not* arise from biological constraints, but predate them. If culture could preexist biological constraints, then the reason to postulate such constraints almost entirely evaporates.⁵

But it is clear, in the light of the arguments above, that there is alternative cultural evolution perspective: that *biological* structure is prior, and that it is cultural forms that adapt, through processes of cultural transmission and variation (e.g., Boyd & Richerson, 2005; Mesoudi, Whiten, & Laland, 2006) to fit biological structure as well as possible. Specifically, the culture is viewed as shaped by endless variation and winnowing, in which forms and patterns which are readily learned and processed are adopted and propagated, whereas forms which are difficult to learn or process are eliminated. Not merely language, but culture in general, is shaped by the brain, rather than the reverse.

Cultural forms will, of course, also be shaped by functional considerations: Just as language has been shaped to support flexible and expressive communication, tool use may have been shaped by efficacy in hunting, flaying, and food preparation. But according to this viewpoint, the fit between learners and culture is underpinned by prior biological “machinery” *that predates that culture, and hence is not itself shaped to deal with cultural problems*. This biological machinery may very well be the product of Darwinian selection, but in relation to preexisting goals. Thus, for example, the perceptuo-motor and planning systems may be highly adapted for the processing of complex hierarchically structured sequences (e.g., Byrne & Byrne, 1993); and such abilities may then be co-opted as a partial basis for producing and understanding language (Conway & Christiansen, 2001). Similarly, the ability to “read” other minds may have developed to deal with elaborate social challenges in societies with relatively little cultural innovation (as in nonhuman primates); but such mind-reading might be an essential underpinning for language and the development of social and moral rules (Tomasello, Carpenter, Call, Behne, & Moll, 2005).

6.3. Conclusion

A key challenge for future research will be to identify the specific biological, cognitive, and social constraints that have shaped the structure of language through cultural transmission; to show how the selectional pressures imposed by these constraints lead to specific patterns in the world’s languages; and to demonstrate how these constraints can explain particular patterns of language acquisition and processing. If we generalize our evolutionary approach to other aspects of cultural evolution and human development, then similar challenges will also lie ahead here in identifying specific constraints and explaining how these capture cross-cultural patterns in development. Importantly, this perspective on human evolution and development does not construe the mind as a blank slate; far from it: We need innate constraints to explain the various patterns observed across phylogenetic and ontogenetic time. Instead, we have argued that there are many innate constraints that shape language and other culturally based human skills but that these are unlikely to be

domain specific. Thus, as Liz Bates put it so elegantly (cited in Goldberg, 2008), ‘‘It’s not a question of Nature versus Nurture; the question is about the Nature of Nature.’’

Notes

1. It might be objected, in the light of the minimalist program in linguistics, that only a very modest biological adaptation specific to language—recursion—may be required (Hauser, Chomsky, & Fitch, 2002). This response appears to fall on the horns of a dilemma. On the one hand, if UG consists only of the operation of recursion, then traditional generativist arguments concerning the poverty of the stimulus, and the existence of language universals, have been greatly exaggerated—and indeed, an alternative, non-UG-based explanation of the possibility of language acquisition and the existence of putative language universals is required. This position, if adopted, seems to amount to a complete retraction of the traditional generativist position (Pinker & Jackendoff, 2005). On the other hand, if the argument from the poverty of the stimulus is still presumed to hold good, with its implication that highly specific regularities such as the binding constraints must be part of an innate UG, then the probability of such complex, arbitrary systems of constraints arising by chance is vanishingly small. To be sure, the minimalist explanation of many linguistic regularities is based on the recursive operation Merge—but, in reality, explanations of specific linguistic data require drawing on extensive and highly abstract linguistic machinery, which goes far beyond simple recursion (Adger, 2003; Boeckx, 2006).
2. Dediu and Ladd (2007) present statistical analyses of typological and genetic variation across Old World languages, suggesting that there may be differences in genetic biases for learning tonal versus sequential phonology. They argue that these biases are unlikely to be due to biological adaptations for language because the same mutations would have had to arise independently several times; instead, they propose that these genetic biases may have arisen for other reasons independent of language but once in place they would slowly have shaped individual languages over generations toward either incorporating tonal contrasts or not. This suggestion fits closely with our argument below that language has been shaped by the brain.
3. It is also possible, of course, that as with pragmatic patterns in general, this pattern may become increasingly conventionalized through use—a typical pattern in grammaticalization (Hopper & Traugott, 1993).
4. This style of explanation, by which traits that are initially acquired during environmental exposure during development may ultimately become innate—that is, independent of environmental input—is known as the Baldwin effect (Baldwin, 1896; see Weber & Depew, 2003, for discussion).
5. Of course, possible co-evolutionary processes between genes and culture complicates the argument but does not change the conclusion. For a more detailed discussion of these issues, in the context of language, see Christiansen and Chater (2008).

Acknowledgments

Nick Chater was supported by a Major Research Fellowship from the Leverhulme Trust and by ESRC grant number RES-000-22-2768. Morten H. Christiansen was supported by a Charles A. Ryskamp Fellowship from the American Council of Learned Societies. We are grateful to Kenny Smith and two anonymous reviewers for their feedback on a previous version of this paper.

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