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Language Is a Complex Adaptive System: Position Paper

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Language has a fundamentally social function. Processes of human interaction along with domain-general cognitive processes shape the structure and knowledge of language. Recent research in the cognitive sciences has demonstrated that patterns of use strongly affect how language is acquired, is used, and changes. These processes are not independent of one another but are facets of the same *complex adaptive system* (CAS). Language as a CAS involves the following key features: The system consists of multiple agents (the speakers in the speech community) interacting with one another.

This paper, our agreed position statement, was circulated to invited participants before a conference celebrating the 60th Anniversary of *Language Learning*, held at the University of Michigan, on the theme *Language is a Complex Adaptive System*. Presenters were asked to focus on the issues presented here when considering their particular areas of language in the conference and in their articles in this special issue of *Language Learning*. The evolution of this piece was made possible by the Sante Fe Institute (SFI) though its sponsorship of the "Continued Study of Language Acquisition and Evolution" workgroup meeting, Santa Fe Institute, 1–3 March 2007.

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The system is adaptive; that is, speakers' behavior is based on their past interactions, and current and past interactions together feed forward into future behavior. A speaker's behavior is the consequence of competing factors ranging from perceptual constraints to social motivations. The structures of language emerge from interrelated patterns of experience, social interaction, and cognitive mechanisms. The CAS approach reveals commonalities in many areas of language research, including first and second language acquisition, historical linguistics, psycholinguistics, language evolution, and computational modeling.

Introduction: Shared Assumptions

Language has a fundamentally social function. Processes of human interaction along with domain-general cognitive processes shape the structure and knowledge of language. Recent research across a variety of disciplines in the cognitive sciences has demonstrated that patterns of use strongly affect how language is acquired, is structured, is organized in cognition, and changes over time. However, there is mounting evidence that processes of language acquisition, use, and change are not independent of one another but are facets of the same system. We argue that this system is best construed as a *complex adaptive system* (CAS). This system is radically different from the static system of grammatical principles characteristic of the widely held generativist approach. Instead, language as a CAS of dynamic usage and its experience involves the following key features: (a) The system consists of multiple agents (the speakers in the speech community) interacting with one another. (b) The system is adaptive; that is, speakers' behavior is based on their past interactions, and current and past interactions together feed forward into future behavior. (c) A speaker's behavior is the consequence of competing factors ranging from perceptual mechanics to social motivations. (d) The structures of language emerge from interrelated patterns of experience, social interaction, and cognitive processes.

The advantage of viewing language as a CAS is that it allows us to provide a unified account of seemingly unrelated linguistic phenomena (Holland, 1995, 1998; Holland, Gong, Minett, Ke, & Wang, 2005). These phenomena include the following: variation at all levels of linguistic organization; the probabilistic nature of linguistic behavior; continuous change within agents and across speech communities; the emergence of grammatical regularities from the interaction of agents in language use; and stagelike transitions due to underlying nonlinear processes. We outline how the CAS approach reveals commonalities in many areas of language research, including cognitive linguistics, sociolinguistics, first and second language acquisition, psycholinguistics, historical linguistics, and language evolution. Finally, we indicate how the CAS approach

provides new directions for future research involving converging evidence from multiple methods, including corpus analysis, crosslinguistic comparisons, anthropological and historical studies of grammaticalization, psychological and neuroscience experimentation, and computational modeling.

Language and Social Interaction

Language is shaped by human cognitive abilities such as categorization, sequential processing, and planning. However, it is more than their simple product. Such cognitive abilities do not require language; if we had only those abilities, we would not need to talk. Language is used for human social interaction, and so its origins and capacities are dependent on its role in our social life (Croft, 2009; Tomasello, 2008). To understand how language has evolved in the human lineage and why it has the properties we can observe today, we need to look at the combined effect of many interacting constraints, including the structure of thought processes, perceptual and motor biases, cognitive limitations, and socio-pragmatic factors (Christiansen & Chater, 2008; Clark, 1996).

Primate species are particularly socially interactive mammals, but humans appear to have emphasized this type of social interaction to an even greater extent. This means that language evolved in the context of an already highly interactive social existence. This intensive interaction suggests that the evolution of language cannot be understood outside of a social context. Language plays a fundamental role in human society and culture, providing the central means by which cultural knowledge is transmitted, elaborated, and reformed over time. Culture itself is at least partly to be understood as a reflection of what humans find interesting and important, which in turn reflects a complex interplay of both evolved biological biases (e.g., we find pleasure in satiating biological desires) as well as cultural biases (e.g., styles of clothing, etc.). Thus, both language and culture are emergent phenomena of an increasingly complex social existence.

The nature of language follows from its role in social interaction. Although social interactions can sometimes be uncooperative and characterized by conflict, they are often characterized by what philosophers of action call shared cooperative activity (Bratman, 1992, 1993, 1997), or joint actions (Clark, 1996). Joint actions are dependent on what might be broadly called *shared cognition*, a human being's recognition that she can share beliefs and intentions with other humans. Joint action involves (among other things) individuals performing individual actions that are intended to carry out a jointly intended shared action, such as moving a piano or performing in a string quartet. Bratman enumerated

several mental attitudes for shared cooperative activity, including meshing of subplans to carry out the joint action, a commitment to help out the other, and shared belief of all of the above.

Finally, Bratman also pointed out that the individual actions that form the joint action must be coordinated for the joint action to be carried out successfully (imagine what would happen if the movers of the piano or the performers in the string quartet did not coordinate their actions). This is where language ultimately comes in. Joint actions pose coordination problems (Lewis, 1969) between the participants. There are various coordination devices that solve the coordination problems of joint actions, of which the simplest is joint attention to jointly salient properties of the environment (Lewis, 1969; Tomasello, 1999). However, by far the most effective coordination device is, of course, for the participants to communicate with each other. However, communication is a joint action: The speaker and hearer must converge on a recognition of the speaker's intention by the hearer (Grice, 1948/1989). Humans have developed a powerful coordination device for communication—that is, convention or, more precisely, a conventional signaling system (Clark, 1996, 1999; Lewis, 1969). Convention is a regularity of behavior (producing an utterance of a particular linguistic form) that is partly arbitrary and entrenched in the speech community. As a coordination device, it solves a recurring coordination problem, namely the joint action of communication. Additionally, communication is in turn a coordination device for any joint action (or other type of interaction) that human beings wish to perform or have happen. On this basis, human culture is built.

Language is a two-level system embedded in the two higher levels of communication (i.e., meaning in the Gricean sense) and joint action (which illocutionary acts are really a simplified example of; see Austin, 1962; Searle, 1969). Language involves the production of signals in a medium such as speech, sign, or writing. This is the regularity of behavior to which the interlocutors jointly attend, called an *utterance act* by Austin. However, these signals are formulated into what Searle called propositional acts and what linguists call words and grammatical constructions. Thus, there are finally four levels in which language operates: producing and attending to the utterance; formulating and identifying the proposition; signaling and recognizing the communicative intention; and proposing and taking up the joint action (Clark, 1992, 1996).

This complex model is in fact fragile, as everyone who has misunderstood someone or has been misunderstood knows. However, there are fundamental reasons why the communicative process is fragile and, therefore, introduces

variation, the substrate for change in language. First, of course, is that we cannot read each other's minds. Equally important is that convention is not airtight as a coordination device (Croft, 2000, 2009). A speaker chooses the words and constructions—the linguistic conventions—to communicate a situation based on the prior use of these conventions in similar situations. The hearer does the same—but the hearer's knowledge of prior uses of the conventions is not the same as the speaker's. Finally, the new situation being communicated is unique and subject to different construals. Although we must not overstate the impossibility of communication—after all, vast civilizations have been constructed on its basis—we cannot deny the indeterminacy of communication, whose product is the ubiquity of language change.

Usage-Based Grammar

We adopt here a usage-based theory of grammar in which the cognitive organization of language is based directly on experience with language. Rather than being an abstract set of rules or structures that are only indirectly related to experience with language, we see grammar as a network built up from the categorized instances of language use (Bybee, 2006; Hopper, 1987). The basic units of grammar are constructions, which are direct form-meaning pairings that range from the very specific (words or idioms) to the more general (passive construction, ditransitive construction), and from very small units (words with affixes, *walked*) to clause-level or even discourse-level units (Croft, 2001; Goldberg, 2003, 2006).

Because grammar is based on usage, it contains many details of co-occurrence as well as a record of the probabilities of occurrence and co-occurrence. The evidence for the impact of usage on cognitive organization includes the fact that language users are aware of specific instances of constructions that are conventionalized and the multiple ways in which frequency of use has an impact on structure. The latter include speed of access related to token frequency and resistance to regularization of high-frequency forms (Bybee, 1995, 2001, 2007); it also includes the role of probability in syntactic and lexical processing (Ellis, 2002; Jurafsky, 2003; MacDonald & Christiansen, 2002) and the strong role played by frequency of use in grammaticalization (Bybee, 2003).

A number of recent experimental studies (Saffran, Aslin, & Newport, 1996; Saffran, Johnson, Aslin, & Newport, 1999; Saffran & Wilson, 2003) show that both infants and adults track co-occurrence patterns and statistical regularities in artificial grammars. Such studies indicate that subjects learn

patterns even when the utterance corresponds to no meaning or communicative intentions. Thus, it is not surprising that in actual communicative settings, the co-occurrence of words has an impact on cognitive representation. Evidence from multiple sources demonstrates that cognitive changes occur in response to usage and contribute to the shape of grammar. Consider the following three phenomena:

1. Speakers do not choose randomly from among all conceivable combinatorial possibilities when producing utterances. Rather there are conventional ways of expressing certain ideas (Sinclair, 1991). Pawley and Syder (1983) observed that "nativelike selection" in a language requires knowledge of expected speech patterns, rather than mere generative rules. A native English speaker might say *I want to marry you*, but would not say *I want marriage with you* or *I desire you to become married to me*, although these latter utterances do get the point across. Corpus analyses in fact verify that communication largely consists of prefabricated sequences, rather than an "open choice" among all available words (Erman & Warren, 2000). Such patterns could only exist if speakers were registering instances of co-occurring words, and tracking the contexts in which certain patterns are used.
2. Articulatory patterns in speech indicate that as words co-occur in speech, they gradually come to be retrieved as chunks. As one example, Gregory, Raymond, Bell, Fossler-Lussier, & Jurafsky (1999) find that the degree of reduction in speech sounds, such as word-final "flapping" of English [t], correlates with the "mutual information" between successive words (i.e., the probability that two words will occur together in contrast with a chance distribution) (see also Bush, 2001; Jurafsky, Bell, Gregory, & Raymond, 2001). A similar phenomenon happens at the syntactic level, where frequent word combinations become encoded as chunks that influence how we process sentences on-line (Ellis, 2008b; Ellis, Simpson-Vlach, & Maynard, 2008; Kapatsinski & Radicke, 2009; Reali & Christiansen, 2007a, 2007b).
3. Historical changes in language point toward a model in which patterns of co-occurrence must be taken into account. In sum, "items that are used together fuse together" (Bybee, 2002). For example, the English contracted forms (*I'm*, *they'll*) originate from the fusion of co-occurring forms (Krug, 1998). Auxiliaries become bound to their more frequent collocate, namely the preceding pronoun, even though such developments run counter to a traditional, syntactic constituent analysis.

Such detailed knowledge of the interactions of grammar and lexicon in usage, which includes knowledge of which words commonly go into which constructions, leads to a conception of lexicon and grammar as highly intertwined rather than separate (Bybee, 1998a; Ellis, 2008b; Goldberg, 2006; Halliday, 1994; Langacker, 1987). The cognitive representations underlying language use are built up by the categorization of utterances into exemplars and exemplar clusters based on their linguistic form as well as their meaning and the context in which they have been experienced (Pierrehumbert, 2001). Because this categorization is ongoing during language use, even adult grammars are not fixed and static but have the potential to change as experience changes (e.g., MacDonald & Christiansen, 2002; Sankoff & Blondeau, 2007; Wells, Christiansen, Race, Acheson, & MacDonald, 2009).

Language change proceeds gradually via localized interactions, but this is not to say that there are no generalizations within or across languages. General properties of language that are both formal and substantive come about in language as in any CAS—through the repeated application of general processes of change. Because the same processes apply in all languages, general resemblances develop; however, the trajectories of change (such as paths of grammaticalization) are much more similar than the resulting states (Bybee, Perkins, & Pagliuca, 1994; Greenberg, 1978).

In the usage-based framework, we are interested in emergent generalizations across languages, specific patterns of use as contributors to change and as indicators of linguistic representations, and the cognitive underpinnings of language processing and change. Given these perspectives, the sources of data for usage-based grammar are greatly expanded over that of structuralist or generative grammar: Corpus-based studies of either synchrony or diachrony as well as experimental and modeling studies are considered to produce valid data for our understanding of the cognitive representation of language.

The Development of Grammar out of Language Use

The mechanisms that create grammar over time in languages have been identified as the result of intense study over the last 20 years (Bybee et al., 1994; Heine, Claudi, & Hünnemeyer, 1991; Hopper & Traugott, 2003). In the history of well-documented languages it can be seen that lexical items within constructions can become grammatical items and loosely organized elements within and across clauses come to be more tightly joined. Designated "grammaticalization," this process is the result of repetition across many speech events, during which sequences of elements come to be automatized as neuromotor

routines, which leads to their phonetic reduction and certain changes in meaning (Bybee, 2003; Haiman, 1994). Meaning changes result from the habituation that follows from repetition, as well as from the effects of context. The major contextual effect comes from co-occurring elements and from frequently made inferences that become part of the meaning of the construction.

For example, the recently grammaticalized future expression in English *be going to* started out as an ordinary expression indicating that the subject is going somewhere to do something. In Shakespeare's English, the construction had no special properties and occurred in all of the plays of the Bard (850,000 words) only six times. In current English, it is quite frequent, occurring in one small corpus of British English (350,000 words) 744 times. The frequency increase is made possible by changes in function, but repetition is also a factor in the changes that occur. For instance, it loses its sense of movement in space and takes on the meaning of "intention to do something," which was earlier only inferred. With repetition also comes phonetic fusion and reduction, as the most usual present-day pronunciation of this phrase is (*be*) *gonna*. The component parts are no longer easily accessible.

The evidence that the process is essentially the same in all languages comes from a crosslinguistic survey of verbal markers and their diachronic sources in 76 unrelated languages (Bybee et al., 1994). This study demonstrated that markers of tense, aspect, and modality derive from very similar semantic sources crosslinguistically. For instance, of the 76 languages, 10 were found to have a future that developed from a verb meaning "go," 10 languages develop a similar meaning from a verb meaning "come," and some languages use a verb meaning "want" (an example is English *will*, which formerly meant "want").

Thus, grammatical categories develop in all languages in this way, but not all of the categories turn out the same. Categories from different lexical sources may have different nuances of meaning; categories that are more or less grammaticalized have different meanings and range of usage. Some rare lexical sources also exist. As odd as it may seem, using a temporal adverb such as "soon" or "by and by" to form a future is rare but does occur.

Given that grammaticalization can be detected as ongoing in all languages at all times, it is reasonable to assume that the original source of grammar in human language was precisely this process: As soon as humans were able to string two words together, the potential for the development of grammar exists, with no further mechanisms other than sequential processing, categorization, conventionalization, and inference-making (Bybee, 1998b; Heine & Kuteva, 2007).

Language change is a cultural evolutionary process (Christiansen & Chater, 2008; Croft, 2000). According to the General Analysis of Selection (Hull, 1988, 2001), evolutionary processes take place at two linked levels: replication and selection. Replicators are units such as a gene, a word, or the practice of marriage that are replicated with some chance for innovation and variation. Selection is a process by which individuals—organisms, or humans as speakers or cultural beings—interacting with their environment cause replication of the replicators to be differential; that is, some replicators are replicated more than others, which in the extreme case leads to fixation of the former and extinction of the latter. In language, linguistic structures—sounds, words, and constructions—are replicated in utterances every time we open our mouths; that is, replication, and variation, occurs when we use language in the service of joint actions between human beings in a community. Due in part to the indeterminacy of communication described earlier, this replication process produces variation. Speakers differentially replicate certain structures through interaction with their environment, namely the situations being communicated and their interlocutors. In the former case, changes in lifestyles lead to the rise and fall of words and constructions associated with those lifestyles (e.g., the rise of *cell* [*phone*] and the fall of *harquebus*). In the latter case, the social identity and the social contexts of interaction lead to the rise and fall of linguistic forms that are associated with various social values by speakers.

First and Second Language Acquisition

Usage-based theories of language acquisition (Barlow & Kemmer, 2000) hold that we learn constructions while engaging in communication, through the "interpersonal communicative and cognitive processes that everywhere and always shape language" (Slobin, 1997). They have become increasingly influential in the study of child language acquisition (Goldberg, 2006; Tomasello, 2003). They have turned upside down the traditional generative assumptions of innate language acquisition devices, the continuity hypothesis, and top-down, rule-governed processing, replacing these with data-driven, emergent accounts of linguistic systematicities. Constructionist analyses chart the ways in which children's creative linguistic ability—their language system—emerges from their analyses of the utterances in their usage history using general cognitive abilities and from their abstraction of regularities within them. In this view, language acquisition is a sampling problem, involving the estimation of the population norms from the learner's limited sample of experience as perceived through the constraints and affordances of their cognitive apparatus, their

human embodiment, and the dynamics of social interaction. The complete body of psycholinguistic research, which demonstrates language users' exquisite sensitivity to the frequencies of occurrence of different constructions in the language input (Gernsbacher, 1994; Reali & Christiansen, 2007a, 2007b) and to the contingencies of their mappings of form and meaning (MacWhinney, 1987), is clear testament to the influence of each usage event, and the processing of its component constructions, on the learner's system (Bybee & Hopper, 2001; Ellis, 2002).

Input and interaction have long been at the center of accounts of second language (L2) learning (Gass, 1997; Larsen-Freeman & Long, 1991). Co-occurrence patterns and their probabilities shape L2 interlanguage (Selinker, 1972) as learners engage in online processing of linguistic stimuli. Initially, these constructions exhibit mutual exclusion (the one-to-one principle; Andersen, 1984). Later, they are categorized, generalized, and, ultimately, analyzed into constitutive forms, although, as in the first language (L1), constructions may simultaneously be represented and stored at various levels of abstraction. L2 developmental sequences are reflective of the linguistic input (Collins & Ellis, 2009; Ellis & Cadierno, 2009)—including Zipfian profiles of construction token and type frequencies (Ellis, 2002; Larsen-Freeman, 1976), cue reliabilities (MacWhinney, 1997), and the salience of the cue and the importance of its outcome in the interpretation of the utterance as a whole (Ellis, 2006; Goldschneider & DeKeyser, 2001). L2 constructions are sensitive to the usual trinity of determinants of associative learning: frequency, recency and context. As with the L1, learners do not merely conform to the L2; they go beyond it, constructing novel forms through analogizing and recombining the patterns (Larsen-Freeman, 1997). Their acquisition of schematic, productive constructions follows the general principles of category learning (Robinson & Ellis, 2007).

Yet despite these similarities, first and second language acquisition differ in significant ways. First, L2 learners come to L2 learning with firmly entrenched L1 patterns (MacWhinney, 1997). Neural commitment to these patterns results in crosslinguistic influence, which manifests itself in a number of ways: the pace at which developmental sequences are traversed, relexification, overgeneralization, avoidance, overproduction, and hypercorrection (Odlin, 1989). The L1 also tunes the learners' perceptual mechanisms so that their learned attention blocks them from perceiving differences in the L2. Second, constructions, as conventionalized linguistic means for presenting different construals of an event, structure concepts and window attention to aspects of experience through the options that specific languages make available to speakers

(Talmy, 2000). Crosslinguistic research shows how different languages lead speakers to prioritize different aspects of events in narrative discourse (Berman & Slobin, 1994). Thus, the conceptual patterns derived from the L1 shape the way that constructions are put together, leading to nonnative categorization and "thinking for speaking" (Slobin, 1996). Third, although both L1 and L2 acquisition are sociocognitive processes (Kramsch, 2002; Larsen-Freeman, 2002), because L2 learners are normally more cognitively mature, the social environment/conditions of learning are significantly different from those of a child acquiring an L1. Thus, understanding the cognitive linguistics of the L2 (Robinson & Ellis, 2007), the psycholinguistics of the L2 (Kroll & De Groot, 2005), and the sociolinguistics of the L2 (Lantolf, 2006) all involve extra layers of complexity beyond those of the L1.

These various factors interact dynamically (de Bot, Lowie, & Verspoor, 2007; Ellis & Larsen Freeman, 2006) to result in a level of ultimate attainment for even the most diligent L2 learner that is usually considerably below what a child L1 acquirer achieves, with some naturalistic L2 acquirers only acquiring a "Basic Variety" characterized by pragmatic word order and minimal morphology (Klein & Purdue, 1992). Usage patterns for grammatical functors in the L1 impede their L2 acquisition because of the shortening that takes place for frequently occurring forms, limiting their perceptual saliency (Ellis, 2006). This is especially true, for example, with bound morphemes. To assist learners in learning these forms, their consciousness must be recruited and their attention directed at these forms through explicit instruction (Ellis, 2005; Larsen-Freeman, 2003). Without such explicit instruction, language use by a high proportion of adult language learners typically means simplification, most obviously manifested in a loss of redundancy and irregularity, and an increase in transparency (McWhorter, 2003; Trudgill, 2001). The emergence of new languages in the form of pidgins and creoles is a more dramatic case of language change, and there are many parallels between the grammatical structures of creoles and the Basic Variety of interlanguage of L2 learners (Becker & Veenstra, 2003; Schumann, 1978). Yet rather than entertaining a deficit view of L2 learning, think instead of adult learners as being multicompetent (Cook, 1991), with different levels of mastery to satisfice (Simon, 1957) in accomplishing what they intend for a variety of languages.

Thus, a CAS perspective on the limited end state typical of adult L2 learners suggests that this results from dynamic cycles of language use, language change, language perception, and language learning in the interactions of members of language communities (Ellis, 2008a). In summary, we have the following: (a) *Usage leads to change*: High-frequency use of grammatical functors causes

their phonological erosion and homonymy. (b) *Change affects perception:* Phonologically reduced cues are hard to perceive. (c) *Perception affects learning*: Low-salience cues are difficult to learn, as are homonymous/polysemous constructions because of the low contingency of their form-function association. (d) *Learning affects usage:* (i) Where language is predominantly learned naturalistically by adults without any form-focus, a typical result is a Basic Variety of interlanguage, low in grammatical complexity but communicatively effective. Because *usage leads to change*, in cases in which the target language is not available from the mouths of L1 speakers, maximum contact languages learned naturalistically can thus simplify and lose grammatical intricacies. Alternatively, (ii) where there are efforts promoting formal accuracy, the attractor state of the Basic Variety can be escaped by means of dialectic forces, socially recruited, involving the dynamics of learner consciousness, form-focused attention, and explicit learning. Such influences promote language maintenance.

Modeling Usage-Based Acquisition and Change

In the various aspects of language considered here, it is always the case that form, user, and use are inextricably linked. However, such complex interactions are difficult to investigate *in vivo*. Detailed, dense longitudinal studies of language use and acquisition are rare enough for single individuals over a time course of months. Extending the scope to cover the community of language users, and the timescale to that for language evolution and change, is clearly not feasible. Thus, our corpus studies and psycholinguistic investigations try to sample and focus on times of most change and interactions of most significance. However, there are other ways to investigate how language might emerge and evolve as a CAS. A valuable tool featuring strongly in our methodology is mathematical or computational modeling.

Given the paucity of relevant data, one might imagine this to be of only limited use. We contend that this is not the case. Because we believe that many properties of language are emergent, modeling allows one to prove, at least *in principle,* that specific fundamental mechanisms can combine to produce some observed effect (Holland, 1995, 1998, 2006a, 2006b; Holland et al., 2005). Although this may also be possible through an entirely verbal argument, modeling provides additional quantitative information that can be used to locate and revise shortcomings. For example, a mathematical model constructed by Baxter et al. (2009) within a usage-based theory for new-dialect formation (Trudgill, 2004) was taken in conjunction with empirical data (Gordon et al., 2004) to show that although the model predicted a realistic dialect, its formation

time was much longer than that observed. Another example comes from the work of Reali and Christiansen (2009), who demonstrated how the impact of cognitive constraints on sequential learning across many generations of learners could give rise to consistent word order regularities.

Modeling can also be informative about which mechanisms most strongly affect the emergent behavior and which have little consequence. To illustrate, let us examine our view that prior experience is a crucial factor affecting an individual speaker's linguistic behavior. It is then natural to pursue this idea within an *agent-based* framework, in which different speakers may exhibit different linguistic behavior and may interact with different members of the community (as happens in reality). Even in simple models of imitation, the probability that a cultural innovation is adopted as a community norm, and the time taken to do so, is very strongly affected by the social network structure (Castellano, Fortunato, & Loreto, 2007, give a good overview of these models and their properties). This formal result thus provides impetus for the collection of high-quality social network data, as their empirical properties appear as yet poorly established. The few cases that have been discussed in the literature—for example, networks of movie co-stars (Watts & Strogatz, 1998), scientific collaborators (Newman, 2001), and sexually-active high school teens (Bearman, Moody, & Stovel, 2004)—do not have a clear relevance to language. We thus envisage a future in which formal modeling and empirical data collection mutually guide one another.

The fact that modeling is a quantitative enterprise obscures the fact that it is as much an art as a science. This is partly because social force laws are not mathematically well established and experimentally confirmed in the way their physical counterparts are. However, the view that language is a CAS, and, in particular, the usage-based framework, does place some constraints on the way that a mathematical or computational model of language use, variation, and change should be constructed.

Clearly, speakers need to be equipped with a prescription for producing utterances that may vary between speakers (a grammar). The unit of variation depends on what is being modeled; for example, in models of language competition (see, e.g., Abrams & Strogatz, 2003; Minnet & Wang, 2008; Reali & Christiansen, 2009; Schulze, Stauffer, & Wichmann, 2008), it is natural to define speakers by the languages they speak. In other cases, a concrete mapping between objects (or concepts) and sounds is appropriate (Hurford, 1989; Nowak, Komaraova, & Niyogi, 2002; Steels, 2000). A more flexible approach adopts abstract units of variation—termed *linguemes* by Croft (2000)—that encapsulate all types of linguistic variations, from single vowel sounds up to

sentence structure (e.g., Baxter, Blythe, Croft, & McKane, 2006; Oudeyer & Kaplan, 2007).

Above all, a usage-based model should provide insight into the frequencies of variants within the speech community. The rules for producing utterances should then be inducted from this information by general mechanisms. This approach contrasts with an approach that has speakers equipped with fixed, preexisting grammars.

We have already argued for the need for an agent-based model that allows for variation in exposure history (perhaps by occupying different positions in a social network structure) and the behavior that results from it. An important point here is that the interactions that mold a speaker's grammar continue throughout her lifetime (for examples of this approach in modeling research, see Baxter et al., 2009; Wedel, 2006). This idea contrasts with approaches in which vertical transmission from fixed speakers in one generation to fluid learners in the next is the dominant mechanism for change (Nowak et al., 2002; Smith, Kirby, & Brighton, 2003). The dynamics in the population of linguistic utterances is therefore not connected in a simple way to that of the underlying human population; hence, the role of natural selection in shaping languages is likely to be diminished compared to what has sometimes been assumed elsewhere (Croft, 2002; Nowak et al., 2002).

Despite these observations, many details of the linguistic interactions remain unconstrained and one can ask whether having a model reproduce observed phenomena proves the specific set of assumptions that went into it. The answer is, of course, negative. However, greater confidence in the assumptions can be gained if a model based on existing data and theories makes new, testable predictions. In the event that a model contains ad hoc rules, one must, to be consistent with the view of language as a CAS, be able to show that these are emergent properties of more fundamental, general processes for which there is independent support.

Characteristics of Language as a Complex Adaptive System

We now highlight seven major characteristics of language as a CAS, which are consistent with studies in language change, language use, language acquisition, and computer modeling of these aspects.

Distributed Control and Collective Emergence

Language exists both in individuals (as idiolect) and in the community of users (as communal language). Language is emergent at these two distinctive but

interdependent levels: An idiolect is emergent from an individual's language use through social interactions with other individuals in the communal language, whereas a communal language is emergent as the result of the interaction of the idiolects. Distinction and connection between these two levels is a common feature in a CAS. Patterns at the collective level (such as bird flocks, fish schools, or economies) cannot be attributed to global coordination among individuals; the global pattern is emergent, resulting from long-term local interactions between individuals. Therefore, we need to identify the level of existence of a particular language phenomenon of interest. For example, language change is a phenomenon observable at the communal level; the mechanisms driving language change, such as production economy and frequency effects that result in phonetic reduction, may not be at work in every individual in the same way or at the same time. Moreover, functional or social mechanisms that lead to innovation in the early stages of language change need not be at work in later stages, as individuals later may acquire the innovation purely due to frequency when the innovation is established as the majority in the communal language. The actual process of language change is complicated and interwoven with a myriad of factors, and computer modeling provides a possible venue to look into the emergent dynamics (see, e.g., Christiansen & Chater, 2008, for further discussion).

Intrinsic Diversity

In a CAS, there is no ideal representing agent for the system. Just as in an economy, there is no ideal representative consumer; similarly, there is no ideal speaker-hearer for language use, language representation, or language development. Each idiolect is the product of the individual's unique exposure and experiences of language use (Bybee, 2006). Sociolinguistics studies have revealed the large degree of orderly heterogeneity among idiolects (Weinreich, Labov, & Herzog, 1968), not only in their language use but also in their internal organization and representation (Dąbrowska, 1997). Mindfulness of intrinsic diversity is helpful for theory construction. As the quest for top-down principles and parametric constraints on linguistic universals stagnates, cognitive linguistics instead turns to the investigation of universals that emerge from the interactions of lower level representations, such as those described in construction-based grammars, and the general cognitive abilities, such as sociability, joint attention, pattern extraction, imitation, and so on, which underlie their acquisition.

Perpetual Dynamics

Both communal language and idiolects are in constant change and reorganization. Languages are in constant flux, and language change is ubiquitous

(Hopper, 1987). At the individual level, every instance of language use changes an idiolect's internal organization (Bybee, 2006). As we define language primarily through dynamical rules, rather than by forces designed to pull it to a static equilibrium, it shares, along with almost all complex systems, a fundamentally far-from-equilibrium nature (Holland, 1995). An open system continues to change and adapt as its dynamics are "fed" by energy coming into the system, whereas a closed system will reduce to a stable state or equilibrium (Larsen-Freeman & Cameron, 2008).

Adaptation Through Amplification and Competition of Factors

Complex adaptive systems generally consist of multiple interacting elements, which may amplify and/or compete with one another's effects. Structure in complex systems tends to arise via positive feedback, in which certain factors perpetuate themselves, in conjunction with negative feedback, in which some constraint is imposed—for instance, due to limited space or resources (Camazine et al., 2001; Steels, 2006). Likewise in language, all factors interact and feed into one another. For instance, language may change in the tug-of-war of conflicting interests between speakers and listeners: Speakers prefer production economy, which encourages brevity and phonological reduction, whereas listeners want perceptual salience, explicitness, and clarity, which require elaboration (Christiansen & Chater, 2008; Cooper, 1999; DuBois, 1985; Lindblom, 1990; Zipf, 1949). Language may evolve for altruistic information sharing and social coordination, or for competition for relevance and for status between coalitions (Dessalles, 2000).

Nonlinearity and Phase Transitions

In complex systems, small quantitative differences in certain parameters often lead to phase transitions (i.e., qualitative differences). Elman (2005) pointed out that multiple small phenotypic differences between humans and other primates (such as in degree of sociability, shared attention, memory capacity, rapid sequencing ability, vocal tract control, etc.) may in combination result in profound consequences, allowing means of communication of a totally different nature. Additionally, in a dynamic system, even when there is no parametric change, at a certain point in a continuous dynamic, system, behavior can change dramatically, going through a phase transition. For example, constant heating of water leads to a transition from liquid to gas, without having any parametric change. In language development, such phase transitions are often observed. Developmental "lexical spurts" often lead to rapid grammatical development (Bates & Goodman, 1997). The S-curve shape of dynamics in language change

is also a kind of phase transition. Several computer models of language origin have demonstrated this feature (Ke, Minett, Au, & Wang, 2002; Kirby, 2000). Grammaticalization as a result of language use may be another example of such phase transitions, in which lexical items become grammatical items. For instance, in the history of English we may observe that the main verb *cunnan* "to know" underwent incremental changes that resulted in a qualitative difference, so that *can* now functions as an auxiliary expressing root possibility (Bybee, 2003). Such changes accumulate gradually as the result of individual speaker utterances and inferences. Yet at a certain point in the shift, processes of change may seem to escalate one another: As the meaning of *can* becomes more abstract and general, the item increases further in frequency, which further drives forward the development of grammatical status.

Sensitivity to and Dependence on Network Structure

Network studies of complex systems have shown that real-world networks are not random, as was initially assumed (Barabási, 2002; Barbarási & Albert, 1999; Watts & Strogatz, 1998), and that the internal structure and connectivity of the system can have a profound impact on system dynamics (Newman, 2001; Newman, Barabási, & Watts, 2006). Similarly, linguistic interactions are not via random contacts; they are constrained by social networks. The social structure of language use and interaction has a crucial effect in the process of language change (Milroy, 1980) and language variation (Eckert, 2000), and the social structure of early humans must also have played important roles in language origin and evolution. An understanding of the social network structures that underlie linguistic interaction remains an important goal for the study of language acquisition and change. The investigation of their effects through computer and mathematical modeling is equally important (Baxter et al., 2009).

Change Is Local

Complexity arises in systems via incremental changes, based on locally available resources, rather than via top-down direction or deliberate movement toward some goal (see, e.g., Dawkins, 1985). Similarly, in a complex systems framework, language is viewed as an extension of numerous domain-general cognitive capacities such as shared attention, imitation, sequential learning, chunking, and categorization (Bybee, 1998b; Ellis, 1996). Language is emergent from ongoing human social interactions, and its structure is fundamentally molded by the preexisting cognitive abilities, processing idiosyncrasies and limitations, and general and specific conceptual circuitry of the human brain.

Because this has been true in every generation of language users from its very origin, in some formulations, language is said to be a form of cultural adaptation to the human mind, rather than the result of the brain adapting to process natural language grammar (Christiansen, 1994; Christiansen & Chater, 2008; Deacon, 1997; Schoenemann, 2005). These perspectives have consequences for how language is processed in the brain. Specifically, language will depend heavily on brain areas fundamentally linked to various types of conceptual understanding, the processing of social interactions, and pattern recognition and memory. It also predicts that so-called "language areas" should have more general, prelinguistic processing functions even in modern humans and, further, that the homologous areas of our closest primate relatives should also process information in ways that makes them predictable substrates for incipient language. Further, it predicts that the complexity of communication is to some important extent a function of social complexity. Given that social complexity is, in turn, correlated with brain size across primates, brain size evolution in early humans should give us some general clues about the evolution of language (Schoenemann, 2006). Recognizing language as a CAS allows us to understand change at all levels.

Conclusions

Cognition, consciousness, experience, embodiment, brain, self, human interaction, society, culture, and history are all inextricably intertwined in rich, complex, and dynamic ways in language. Everything is connected. Yet despite this complexity, despite its lack of overt government, instead of anarchy and chaos, there are patterns everywhere. Linguistic patterns are not preordained by God, genes, school curriculum, or other human policy. Instead, they are emergent—synchronic patterns of linguistic organization at numerous levels (phonology, lexis, syntax, semantics, pragmatics, discourse, genre, etc.), dynamic patterns of usage, diachronic patterns of language change (linguistic cycles of grammaticalization, pidginization, creolization, etc.), ontogenetic developmental patterns in child language acquisition, global geopolitical patterns of language growth and decline, dominance and loss, and so forth. We cannot understand these phenomena unless we understand their interplay. The individual focus articles that follow in this special issue illustrate such interactions across a broad range of language phenomena, and they show how a CAS framework can guide future research and theory.

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