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Language Origin from an Emergentist Perspective

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In recent decades, there has been a surge of interest in the origin of language across a wide range of disciplines. Emergentism provides a new perspective to integrate investigations from different areas of study. This paper discusses how the study of language acquisition can contribute to the inquiry, in particular when computer modeling is adopted as the research methodology. An agent-based model is described as an illustration, which simulates how word order in a language could have emerged at the very beginning of language origin. Two important features of emergence, heterogeneity and nonlinearity, are demonstrated in the model, and their implications for applied linguistics are discussed.

INTRODUCTION

Inquiry into language origin

The origin of language is one of the most intriguing and long-standing questions in our understanding of human nature. Many of the early inquiries, however, are little more than just-so stories. There had been so many speculative conjectures by the time Darwin published *On the Origin of Species* that the Linguistic Society of Paris issued a ban on publications about the origin of human language in 1866. It stated that 'La Société n'admet aucune communication concernant, soit l'origine du langage, soit la création d'une langue universelle' ['The Society will accept no communication dealing with either the origin of language or the creation of a universal language'] (Stam 1976). Only in recent decades has the investigation of the origin of human language returned as a scientific and collaborative enterprise. Since the late 1990s, the interest in language origin has increased dramatically, and a wide range of disciplines are joining in the endeavor to construct a plausible picture for when, where, and how language originated, and how it has evolved (Cangelosi and Parisi 2001; Christiansen and Kirby 2003; Hawkins and Gell-Mann 1992; Hurford *et al*. 1998; Knight *et al*. 2000; Minett and Wang 2005; Wray 2002a).

Among these disparate disciplines, genetic and archaeological studies propose tentative answers to the '*when*' of language origin. One hypothesis speculates that when anatomically modern humans first developed, the genetic disposition for language processing was already present. The earliest human fossils discovered so far suggest that this occurred at least 160,000 years ago (White *et al.* 2003). This date is close to the time proposed by the genetic studies which use the divergence of mtDNA and Y chromosome in current human populations to estimate the time as of the Common Human Ancestor (Cann *et al.* 1987; Thompson *et al.* 2000). Another scenario points at a later time, about 40–50,000 years ago, at which time there seemed to be significant population expansion (Cavalli-Sforza 1997) and cultural explosion as attested in cave paintings, burial rituals, and so on (Klein 1999), as well as long-distance sea crossings from Asia to Australia (Davidson and Noble 1992), all pointing to the availability of a new effective means of communication.

Comparative studies on animals and their means of communication inform us about '*where*' human language may have started. It was previously believed that language was the result of genetic mutations specific in humans and that there was no continuum between human language and other animals' communication systems. However, many capacities which were considered human-specific for language have been found in other animals in varying degrees. For example, the descent of the larynx is found in other animals such as male red deer and chimpanzees, and it is unlikely to have evolved specifically for human speech (Hauser and Fitch 2003). The advances in genetic studies (e.g. comparison of chimpanzee and human genomes) and primatology (e.g. de Waal 2005) have revealed striking similarities in the genetic compositions, social behaviors, and cognitive capacities that our closest living relatives share with us.

Historical linguistics shed light on '*how*' language could have emerged by showing how languages changed in the past, as does research on the genesis of pidgins and creoles (Mufwene 2001), as well as on the development of sign languages in isolated communities (Sandler *et al.* 2005; Senghas *et al.* 2004). The phenomenon of 'grammaticalization', by which content lexical words change into function words (Hopper and Traugott 1993), has been found to be pervasive across these investigations, suggesting that the earliest forms of language had no function words or grammatical morphemes, and the complicated syntactic system evolved from simple lexical items throughout the history of language change.

In parallel to the study of language in the past, developmental psychology, cognitive sciences, and neurosciences try to understand how language is acquired and processed by humans at present. The interactions are mutual, with researchers in these areas being interested in language origin (Elman *et al.* 1998; MacWhinney 1999) in order to inform their theories. In addition to these empirical studies, computer modeling has joined the endeavor in recent years (Cangelosi and Parisi 2001; Kirby 2002a; Wagner *et al.* 2003; Wang *et al.* 2004).

This paper will focus on the last two areas. That is, we are concerned with ways in which the study of language acquisition can contribute to explaining language origin from an emergentism perspective, and how computer modeling as a new methodology can be used for such purposes.

Specifically, we discuss an agent-based model, informed by a range of findings from language acquisition, to test hypotheses concerning the emergence of word order. At the end of the paper, we discuss why and how the study of language origin is relevant to applied linguistics. Although at first glance it might appear that these two research areas have little to do with each other, our models illustrate how understanding the origin of language informs our theories of language use, language learning, and language instruction.

EMERGENTISM

There are two main approaches to understanding language origin. The first focuses on the biological bases: what are the physiological, cognitive, and neurological mechanisms for language learning and language use? While it is clear that there have to be some biological prerequisites, it remains to be seen how many of these are human specific and language specific. Pinker and Bloom (1990) argue that humans are born with a language faculty, also called a universal grammar (UG), as a result of biological adaptation specific to language and to humans. However, there has been a great deal of debate over the actual components of UG. While earlier proposals for UG were mostly concerned with syntax, dealing with a set of highly abstract principles and parameters, recently the focus has shifted to more concrete components of language, such as the conceptual system, speech perception and production mechanisms, and the ability to store and process a large number of symbols. A recent review article on language evolution by Hauser *et al*. (2002) has been very influential in these regards, but their hypothesis that recursion is the only language-specific aspect remains highly controversial (Pinker and Jackendoff 2005).

The second research focus concerns the social and cultural aspects of language origin. This approach pays more attention to factors such as interactions between individuals, social structures, patterns of cultural transmission, and their effect on the process of evolution of language in the community. It is argued that language could have evolved from simple communication systems through generations of learning and cultural transmission, without new biological mutations specific to language. While the human species may have evolved to be capable of learning and using language, it is more important to recognize that language itself has evolved to be learnable for humans (Christiansen 1994; Deacon 1997).

The two approaches to language origin that we have outlined above find a parallel in language acquisition research and the long-standing opposition between *nativism* and *empiricism*, or between *nature* and *nurture*. In recent decades, emergentism has appeared to 'replace the traditional opposition with a new conceptual framework, explicitly designed to account in mechanistic terms for interactions between biological and environmental processes' (MacWhinney 1999: X). It is viewed that language emergence in individual learners can be explained by 'simple learning mechanisms, operating in and across the human systems for perception, motor-action, and cognition as they are exposed to language data as part of a communicatively-rich human social environment by an organism eager to exploit the functionality of language' (Ellis 1998: 657). Emergentism emphasizes the importance of integrating the two approaches: on the one hand, we have to sort out the sufficient and necessary innate abilities in humans which enable language acquisition, and, on the other hand, we need to understand the environment's profound impact on learners, the learning process as well as the end product of learning.

Emergentism also provides the study of language origin with a framework for integrating the two approaches reviewed above. Language origin and language acquisition are both emergent, albeit at two different time scales: phylogeny over tens of thousands of years at the macro-level, and ontogeny over a few years at the micro-level. These two levels of emergence inform each other.

It is highly unlikely that language could have sprung spontaneously from a group of early humans within one generation.[1] A full-fledged language should have agglomerated its complexity gradually over the course of many generations, which means that the learning of the younger generations must have played a crucial role in the process. The initial biological condition for language acquisition of humans today should be the same as, or at least very close to, that of humans at the time when language first developed (Schumann and Lee 2005).[2]

If the initial condition for language acquisition is a universal grammar (UG) which is specific to language, the task for the study of language origin becomes to explain the origin of UG: why and how it was selected biologically. Recent research, however, has argued that language acquisition can be better explained as a lexically-based construction process. The initial condition of language acquisition may require only a set of general cognitive abilities, non-specific to language, such as symbolization, intention reading, pattern finding, imitation, and crossmodal association, etc. (Tomasello 2003). Instead of having a language instinct, humans are better described as having a communication instinct and an instinct for learning in general.

Moreover, if the initial condition for language acquisition is indeed far less than an autonomous syntax module, then the key to explaining language origin lies in examining the dynamic *processes* of emergence, instead of dwelling on the properties of individuals. This shift of focus of investigation is in line with a general paradigm shift in science since the mid-twentieth century (Holland 1998). As Stuart Kauffman points out,

> The past three centuries of science have been predominantly reductionist, attempting to break complex systems into simple parts, and those parts, in turn, into simpler parts. The reductionist program has been spectacularly successful, and will continue to

> be so. But it has often left a vacuum: How do we use the information gleaned about the parts to build up a theory of the whole? The deep difficulty here lies in the fact that the complex whole may exhibit properties that are not readily explained by understanding the parts. The complex whole, in a completely non-mystical sense, can often exhibit collective properties, 'emergent' features that are lawful in their own right (Kauffman, 1995, p. vii).

Emergentism pervades the complex adaptive systems in nature and human societies: snowflakes, honeybee combs, termite mounds, schools of fish, flocks of birds (Camazine *et al*. 2001), and economies and ecosystems (Holland 1998), are all emergent phenomena. In these complex systems, the emergence of complex structures at the global level is explained as the result of the long-term iterative interactions among the individuals inside the systems. The individuals do not have innate knowledge or a blueprint of the global structures, but each performs simple actions with limited knowledge of the local environment without any central control. Many computer models have successfully demonstrated such processes (Holland 1998).

AGENT-BASED MODELING OF LANGUAGE ORIGIN

Computer modeling is a widely used methodology in the natural sciences and engineering in order to simulate complex real-world systems. It provides 'virtual experimental laboratories' to 'run realistic, impossible, and counter-factual experiments,' and 'test internal validity of theories' (Cangelosi and Parisi 2001: 2–3). In order to build a model based on a chosen theory, the modeler needs to make all the assumptions in the model explicit and implementable. The models are usually highly idealized and simplified, so that a modeler can run controlled experiments on a number of parameters and different initial conditions, in order to examine their effects on the system behavior.

In some situations, models may seem circular: the modelers build in what they expect to see, and therefore, the results are not unexpected. However, as Nettle (1999) points out, the interest in modeling does not lie in what the model can be made to do, but rather what assumptions and initial conditions have to be included to make the model produce the desired result. More importantly, there are times when the simulation leads to dead-ends or unexpected outcomes. Then the modelers have to carefully examine and modify the existing assumptions or parameters. Modelers can identify new directions for empirical studies in order to address problems arising from the failure of the models. The beauty of modeling does not lie in producing results which confirm the hypotheses, but more in the process of building the model.

Agent-based modeling (ABM)[3] is a type of computer modeling which has been widely used and proved to be fruitful in offering new insights into the study of complex systems including man-made systems such as stock markets and traffic jams, and natural systems such as immune systems, ant colonies, etc. In an agent-based model, there is usually a group of individual components—the 'agents'—which are autonomous and share similar basic characteristics. The agents constantly interact with each other based on local information and simple rules. These simple interactions often lead to the emergence of some global structural patterns which cannot be predicted simply from the properties of the individual agents. Agent-based models have certain advantages over traditional analytical models. For example, analytical models often assume homogeneity within the system due to the limitation of mathematical formulations, and the interest of study is the equilibrium state or the average characteristics of a system. In contrast, agent-based models study the transient behaviors of a system before it reaches equilibrium. Agents are not necessarily homogenous, but differ in their properties or behaviors. This heterogeneity is commonly observed in real systems. Moreover, while analytical models often assume infinite populations, agent-based models take into account finite populations with different population structures, which have been shown to have a profound influence on system dynamics.

Although computer modeling is well-established in the connectionist study of language acquisition, it is a relatively recent, although rapidly burgeoning, development in the study of language origin (Kirby 2002a; Wagner *et al.* 2003; Wang *et al.* 2004).[4] Computer models may adopt different paradigms of language evolution, being a biological (Nowak *et al.* 2001) or cultural transmission process (Kirby 2002b), or a co-evolving process (Munroe and Cangelosi 2002). Most models study the emergence of one of the subsystems of language, for example phonology, vocabulary, or syntax. Many of these models are agent-based models. For example, Steels (1996) and Ke *et al.* (2002) study the emergence of a simple lexicon. These models demonstrate how a set of arbitrary associations between meanings and forms can be established as conventions through imitation and self-organization in a group of agents. While these models assume the pre-existence of meanings, Steels and Kaplan (2002) present models where meanings are not prefixed but co-evolve with the meaning–form associations.

There have also been models investigating the emergence of sound systems, such as de Boer (2001) for vowel systems, and Oudeyer (2002) for syllabic structures. Although these models consider only sounds, without the presence of meanings, they can produce results very close to the universal distributions of sound systems found in real languages, which suggests that the assumptions in these models are highly probable. A few models have worked on the emergence of higher-level linguistic structures: Batali (1998), Kirby (2000), and Gong *et al.* (2005) study the emergence of compositionality, and Kirby (2002b) simulates the emergence of recursive structures. These models are all highly simplified, and the assumptions can be controversial, but they are important initial steps in the area of modeling language origin.

In the agent-based models of language origin, individual language users are the agents. These agents share similar characteristics, for example, articulation and perception of sounds (de Boer 2001; Oudeyer 2002), or some general learning mechanisms such as imitation and association (Ke *et al*. 2002), or recurrent pattern extraction (Gong *et al*. 2005; Kirby 2000). The representation of the language in the agents is usually one of two types. One involves neural networks, which are characterized by their distributed nature. The input of the network may be the meaning represented by some grounded features of physical objects such as color, size, and shape, etc., and the output the corresponding linguistic form or signal (Cangelosi and Harnad 2000). Conversely, the input of the network may be the signal and the output the meaning (Batali 1998). The other type of representations is symbolic, where meanings and forms are all represented by discrete symbols, such as lexical mappings (Steels 1996), or syntactic rules (Kirby 2000).

In an agent-based model, while agents are assumed to be governed by similar underlying mechanisms, they do not necessarily behave in exactly the same way. For example, they do not necessarily develop exactly the same language. Furthermore, even though they appear to share a language, their internal representations may be different. What the agents learn and how they use their language depend on the histories of their interactions with the environment, which highly depend on their social status and social connections, as evidenced by empirical findings in studies of social networks (Milroy 1987). However, the factors that cause heterogeneity have not been much explored in the models of language origin, although there have been some attempts in models of language change (Ke 2004; Nettle 1999).

In addition to the consideration of implementing individual agents, 'it is necessary to move from the study of individual (idealized) language learners and users, endowed with a LAD and acquiring an idiolect, to the study of populations of such generative language learners and users, parsing, learning and generating a set of idiolects constituting the language of a community' (Briscoe 2002: 257). The interactions between agents may take place in a random way, that is each time two randomly selected agents interact (Batali 1998). Alternatively, agents may interact only with the nearest neighbor (Kirby 2000), or with a number of neighbors within a certain distance (such as models of language change, e.g. Nettle 1999). Gong *et al*. (2004) is one of the few studies which examine the relationship between language and social structures. It is shown that different communication strategies lead to different social structures: a random interaction strategy results in an almost fully-connected network and a strategy with a preference to a popular agent in a local world results in a more sparse and segregated network.

MODELING THE EMERGENCE OF WORD ORDER

We now introduce an agent-based model presented in Gong *et al.* (2005), which simulates how word order could have emerged, to illustrate how computer modeling could shed new light on the study of language origin and language acquisition. All languages organize words in a certain sequential order. Even in languages which have rich case marking and more flexible word orders, such as Latin, there is still a dominant order. In syntactic theory, word order involves more than putting individual words in a certain order; word order entails rules of how categories of words should be put together. Therefore, the knowledge of word order presumes the existence of knowledge of syntactic categories. Nativists hypothesize that children have an innate linguistic knowledge about syntactic categories, and when their knowledge of word order is triggered by linguistic input, they are able to productively construct multi-word utterances from very early on.

However, this view has been challenged by many in-depth analyses of early multi-word utterances in children's speech data (Tomasello *et al.* 1997; Lieven *et al.* 1997; Wray 2002b; Tomasello 2003). It is argued that children acquire syntactic categories from generalization of early lexically-based constructions. Children's first multi-word utterances are found to be holophrases imitated from adults' speech, such as 'I dunno', 'go-away', etc. whose internal structures are not recognized by children. Later, at around 18 months, many children start to combine two words or holophrases, for example, 'ball table', 'baby milk'. Also, around the same age, many of the multi-word utterances appear as pivot schemas, such as 'more ___' and '____ it', where one event-word is used with a wide variety of object labels. Tomasello *et al.* (1997) demonstrated the productivity of such pivot schemas, as children can apply novel names to these schemas immediately after the names are taught. For example, when taught a novel object label 'Look! Wug!', the children were able to produce sentences like 'Wug gone' and 'More wug'. However, children at this age do not make generalizations across various pivot schemas, and they do not have the syntactic categories yet.

At a later stage, around 2 years old, children go beyond pivot schemas. They can understand 'make the bunny push the horse' which has to depend on the knowledge of word order. Also, they can produce utterances which are consistent with the canonical word order, as evidenced by utterances from overgeneralization such as 'don't giggle me'. This type of overgeneralization has been used as an argument for nativism. However, such errors are rarely seen in children's speech before about 3 years old, which suggests that the knowledge of word order does not come from the very beginning. Furthermore, Akhtar (1999) showed that children around 2–3 years old would correct an utterance which violates the English canonical order if the verb is a familiar verb such as 'push', but they did not correct novel verbs such as in 'Big Bird the car gopping!'. Interestingly, older children (4 years old) tend to correct word order to match the canonical order, which implies that by this age they have mastered the word order as an abstract syntactic structure.

The findings from language acquisition described above have led to a hypothesis for language origin, which suggests that language may first start from holistic utterances, from which words or phrases/schemas are extracted as recurrent patterns, and later used in combination to express new meanings (Wray 2002b). This hypothesis differs from the scenario proposed by Jackendoff (1999) and others which suggests that there is a one-word stage when single symbols, that is words, are used for communication, and later words are concatenated following some basic word orders. A number of models have been reported to simulate this process using agent-based models (Gong *et al*. 2005; Kirby 2000). In the following, we introduce a model adopted from Gong *et al*. (2005). We discuss the assumptions of agents' capacities, the flow of the simulation process and some preliminary results.

Assumptions of the model

Before building a model, one has to take the important step of deciding on a set of explicit assumptions to be included. Our model makes the following assumptions about agents' capacities and principles governing their actions:

Agents have the same semantic space and pre-existing semantic categories

It has been shown that children can understand concepts about space, time, and numbers, etc. from very early on, and comprehend the distinction between action and object (Tomasello 2003). Similarly, we assume that agents are exposed to the same environment, and they have internalized a set of simple concepts or meanings which are salient in the physical environment. For the sake of simplicity, the meanings considered in the current model are descriptions of some simple events, such as 'who is doing what', for example 'the tiger is sleeping', 'the tiger is eating a rabbit'. Each agent has a fixed number of pre-existing meanings. These meanings are represented in the form of predicate constructions, and only two types of meanings are considered, predicate<actor>[5] and predicate<actor, patient>. Thus, the above two meanings are represented as '*sleep<tiger>*', '*eat<tiger, rabbit>*'. Agents can recognize the semantic distinction between *entity or object* (e.g. tiger, meat) and *action* or *event* (e.g. eat, sleep), as well as the distinctions between actor, patient, and predicate. Note that these semantic categories do not necessarily correspond to the syntactic categories, for example noun and verb, as the latter are generalized based on the ordering of words. At the beginning, different predicates may have different orderings, and one predicate may have different orderings when combined with different actors.

Agents are equipped with a symbolic communication ability

Humans are a symbolic species (Deacon 1997). Children are able to understand and learn symbols to represent the outside world and to communicate from very early on. In the model, it is assumed agents share a few established holistic signals, similar to the alarm calls observed in monkeys and other animals. A holistic signal has no internal structure and each utterance as a whole is associated with a certain meaning. Moreover, the agents are able to create new signals voluntarily by associating an intended meaning with an utterance which is constructed from a random concatenation of available sounds. Each sound that agents are able to produce comes from a limited set. In the model, the basic sound unit is assumed to be a syllable, rather than a phone or a phoneme used in linguistic analyses. For the sake of simplicity, the sound is represented in an abstract manner by a numerical value, and the relationship between sounds is ignored in the present construction. For example, an agent creates a holistic signal */1 4 12/* to express the meaning '*sleep<tiger>*', or */3 7 14 2/* for '*eat<tiger, rabbit>*'. Each agent has his own way of creating novel holistic signals. However, this ability is incipient and agents only have a low probability to create novel signals.

Agents can read each other's communicative intentions

It has been shown that infants at the end of their first year of life start to engage in all kinds of interactions with joint attention with others, including gaze following, social referencing, imitation of actions on objects, and gestural communication (Tomasello 2003). Therefore, we assume that an agent acting as a listener in the model always tries to infer a meaning from the received utterance sent by a speaker. However, agents do not have direct access to other agents' minds. In other words, the listener does not know the exact meaning intended by the speaker, and his interpretation of a received utterance is only based on his own knowledge and the information from the environment. In each communicative instance, the listener is provided with one environmental cue, which may or may not be the same as the intended meaning. Thus, the intended meaning is given probabilistically to the listener. After his analysis of the received utterance, the listener then sends some simple feedback, similar to a nodding or a facial expression of confusion, to indicate if he is confident about his own understanding of the speaker's utterance. The speaker does not know what the listener's actual interpretation is, and he only assesses the success of the interaction based on the feedback received from the listener.

Agents have imitation ability

Infants have been shown to be 'imitation generalists', as they are very good at vocal and behavioral imitation from very early on (Meltzoff 1996).

By 14 months of age, they can imitate the actions performed by adults, such as 'put teddy to bed', as well as the speech sounds they hear around them. In the model, when an agent hears a novel utterance in an interaction, he imitates it, that is he copies the utterance to his list of rules. However, the listener does not know exactly what the speaker means by the utterance. He interprets the meaning of the utterance on the basis of his own linguistic analyses or the environmental cue(s). In other words, any imitation is done only on the basis of forms, not necessarily associated with the intended meaning.

Agents continually detect recurrent patterns

Recurrent patterns are considered 'building blocks' in terms of complexity theory (Holland 1998), which is an innate human disposition: 'Any human can, with the greatest ease, parse an unfamiliar scene into familiar objects' (Holland 1998: 24). Studies on children's cognitive development have identified these skills, pattern-finding, or categorization, in very young children (Tomasello 2003). In this model, agents are able to detect recurrent patterns from the existing set of holistic signals, that is to say meaning–utterance mappings. If there are recurrent parts of utterances in signals which also share some meaning components, then agents can extract these recurrent patterns from the holistic signals, and establish a smaller unit of meaning–utterance mapping. For example, if an agent has two holistic rules:

'eat<tiger, rabbit>'↔/3 7 14 2/
'eat<tiger, deer>'↔/9 8 14 2/

the agent extracts a phrasal rule *'eat<tiger, #>'↔/# 14 2/* (the # stands for a variable which can be filled in with different entities). The agents only extract subunit rules when they recur in different rules. In other words, in the above case, the agent does not continue to segment the holistic signal to get *'rabbit'* ↔/3 7/or 'deer' ↔/9 8/, unless the same parts occur at least once more in other holistic rules. This design is somehow arbitrary, as the other situation—direct decomposition of remaining subunits—is possible. The current model, however, does not implement this as there is no empirical evidence suggesting this possibility so far. It would be interesting for future studies to compare the outcome of these two different types of pattern extraction.

Agents have sequencing ability

Agents have an innate ability to deal with combinations of elements or events occurring in temporal sequences. This sequencing ability is domain general, and found in non-human primates, which also appear to be capable of encoding, storing, and recalling fixed sequences of either motor actions or visual stimuli (Conway and Christiansen 2001; Terrace 2002). Therefore, we assume that agents are able to concatenate strings and units of utterances according to specific consistent sequences. As mentioned earlier, two types of order rules are considered here; one resembles intransitive verbs such as '*sleep*<*tiger*>', and the other transitive verbs such as '*eat*<*tiger, rabbit*>'. The agents know how to combine these semantic elements once they have words to express the individual meaning components. For ease of presentation, we still denote these order rules with the symbols S, V, and O, but note that they do not represent the conventional syntactic categories. There are two possible orders for the first type of meanings: SV and VS; and six possible orders for the second type: SVO, SOV, VSO, VOS, OSV, OVS.

Agents' behavior is governed by rule competition

In language acquisition, competition occurs at all levels of linguistic processing (MacWhinney 2002). For example, language comprehension is based on the detection of a series of cues which compete with each other based on their strength determined by their reliability and availability. Similarly, this model incorporates such competition among rules both in production and comprehension. Each lexical rule and word order rule is associated with a value of a particular strength, which is within the range of 0 and 1. At the beginning of the process, all agents have six pre-given holistic rules (which are arbitrarily set by the program, for example '*eat*<*tiger, rabbit*>'↔/3 7 14 2/),[6] and eight sequencing orders (SV, VS, SVO, SOV, VSO, VOS, OSV, and OVS), each with a small but equal strength. Through occasional creation by agents themselves, imitation from others, and rule extraction from detected patterns, agents increase their rule repertoires gradually. When there is more than one way to express one meaning or interpret one received utterance, by using a holistic signal, or a combination of lexical rules together with a word order rule, the rules compete with each other. The winning rules are strengthened by a given amount after each interaction, and the strength of the losing rules is decreased by an equivalent amount. Also, rules' strengths decrease regularly by a small amount every time step, as rules may be forgotten if they are not used often enough. Therefore, the rule with a higher strength is more likely to be chosen in later situations, following a 'the rich gets richer' pattern. In the long run, rules differ in their fates: some become more and more strong and stabilized, while some get disused and even disappear from the repertoire.

Implementation of the model

Figure 1(a) shows the flow of the simulation process of the model. A group of agents is first initiated as a population, each is prescribed with the above assumptions. In one run of the simulation, the population goes through a fixed number of time steps (*NumStep*). In each step, a number of pairs of agents (*NumPair*) are randomly chosen and each pair interacts for a number of communication episodes (*NumInter*).

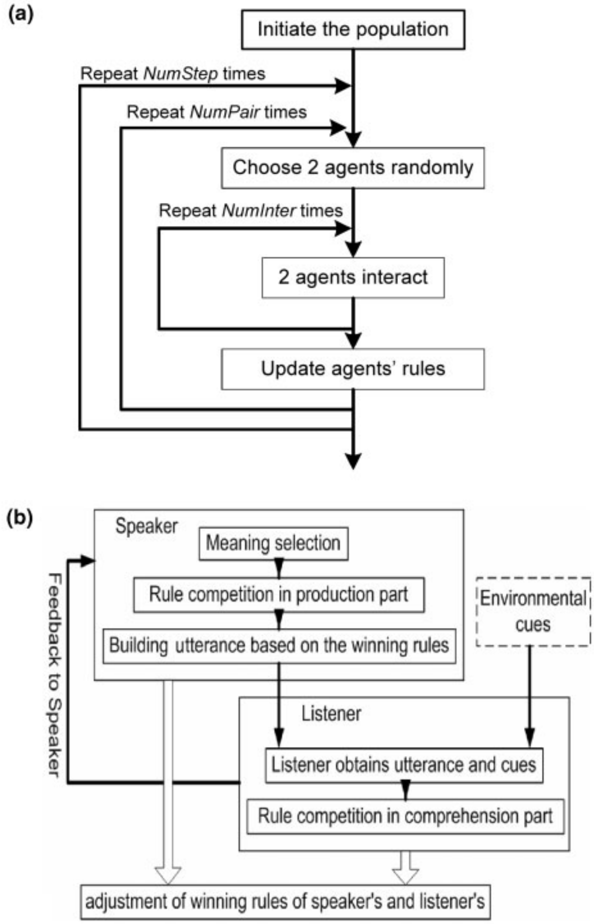

Figure 1: (a) The flow chart of one simulation run of the model; (b) The flow chart of one interaction.
Source: replicated from Gong *et al.* 2005

Figure 1(b) shows how an interaction proceeds. The speaker randomly chooses a meaning to convey to the listener. If the speaker's current linguistic repertoire does not provide a means to express this meaning, he will get a chance, under a probability, to create a random holistic signal to convey the meaning. In contrast, if the speaker has already had rules (either word or phrase rules) for all the components of the intended meaning, he combines these rules according to a certain order rule. If there is more than one choice, the rules compete with each other. The winning rules are used for production, and if later the speaker receives a feedback signal from the listener showing his confidence in understanding the speaker's utterance, these rules' strengths will be increased by a small amount, set as 0.1 in the model.

Upon receiving the speaker's utterance, the listener tries to interpret it by going through his own repertoire of rules. If the existing rules do not allow the listener to decompose the utterance, he guesses the meaning of the utterance from the given environmental cues, and incorporates this mapping into his rule repertoire. Agents can thus gradually increase the number of meanings they can express through this imitation process.

In each interaction, since the listener and speaker have shared attention, the listener may obtain one environmental cue from the context of the interaction. For example, when the speaker sends an utterance */3 7 14 2/* intending a meaning *'eat<tiger, rabbit>'*, the listener may receive an environmental cue, such as *'hungry<tiger>'*, or *'dead<rabbit>'*. If he does not have a rule to interpret the utterance, he may subsequently associate the received utterance with the given environmental cue. In the model, for ease of implementation, the given environmental cue for each communication is selected from the possible meanings, provided that the intended meaning is the same as the cue under a probability, which is set at 0.8 in the current simulation. This implementation of the probabilistic availability of the intended meaning mitigates the problems in the early models (e.g. Kirby 2000) which hold an unrealistic assumption of 'mind-reading', that is agents can always know what others have exactly in mind (Gong *et al*. 2005).

If the listener happens to have more than one interpretation for the received utterance, he will choose the one with the strongest combined strength, and adjust the strengths of the rules accordingly. Then the listener gives feedback to the speaker to show his confidence about his own understanding, to make the speaker decide whether or not to strengthen the rules used in this communication event. The interactions continue until the given number of interactions and steps have been reached.

Simulation results

In the model, there are 20 agents in the population; each agent has 48 pre-existing meanings for communication, and six pre-existing holistic signals from the start. In each step, 200 pairs of agents interact, and each pair communicates 20 times in one interaction. The simulation continues for 400 time steps. With this parameter setting, the model is run 20 times with different random initial conditions. Figures 2 and 3 show the results of one typical run. Figure 2 shows three measures of the development of the communication system in the population, including the holistic expressivity and combinatorial expressivity (i.e. the average percentage of meanings that can be expressed by holistic and combinatorial signals respectively), and comprehensibility (i.e. the average percentage of meanings out of the total 48 possible meanings that agents can understand). The figure shows that the agents, starting from only six innate holistic signals, gradually increase their expressivity by adding new holistic signals and compositional signals. The holistic signals grow at the beginning, but

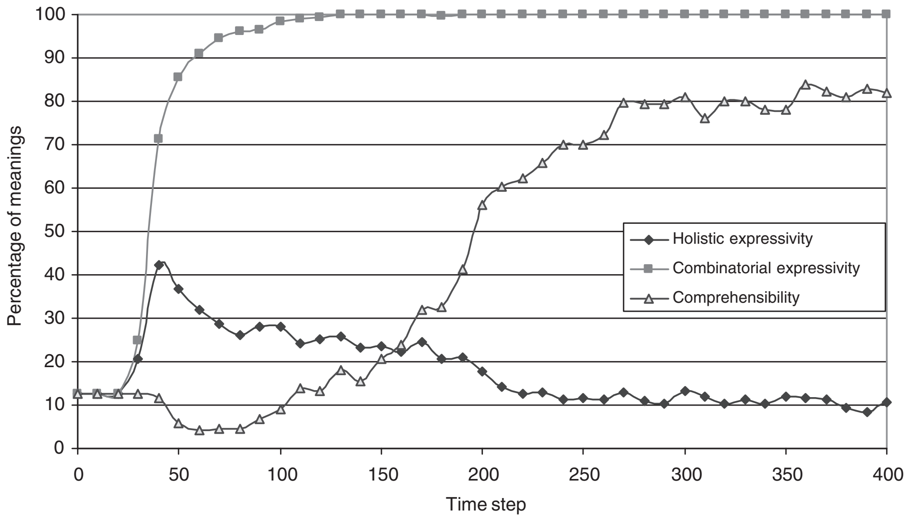

Figure 2: The growth of rule expressivity of holistic signals and combinatorial signals, and comprehensibility in a typical run

only to a certain extent, and then they gradually drop out from use. However, the holistic signals never disappear entirely, and a small number of them persist in the agents' repertoires. At the end of the simulation, the agents can express all the meanings with compositional signals. As for comprehensibility, at the beginning, the mutual understanding between agents only relies on the six pre-given holistic signals, and this situation lasts for more than 30 time steps. Then abruptly a number of new rules are created, and the comprehensibility decreases temporarily. The comprehensibility starts to increase again around the 80th time step, and continues to grow gradually. It reaches more than 80 per cent by the 400th time step.

Figure 3 shows the changes in strength of the different word orders and the emergence of a dominant order from this typical run. At the beginning, all possible orders compete with each other and their strengths fluctuate. Among the orders for the predicate<actor, patient> meanings, the order OVS is the dominant one for a while, but around the 160th time step, another order, VSO, takes the dominant position, and continues to increase its strength until it finally stabilizes as the only order. During the shift in dominant word order, no external force is applied to trigger the change; it happens spontaneously as a result of the random interactions among agents. Similarly, in the competition between SV and VS, the two orders co-exist for more than 100 steps, and around the 150th step, SV takes off and quickly outperforms VS.

At the end of the simulation, the agents reach a high mutual understanding value (over 80 per cent) across all possible pairs, but their

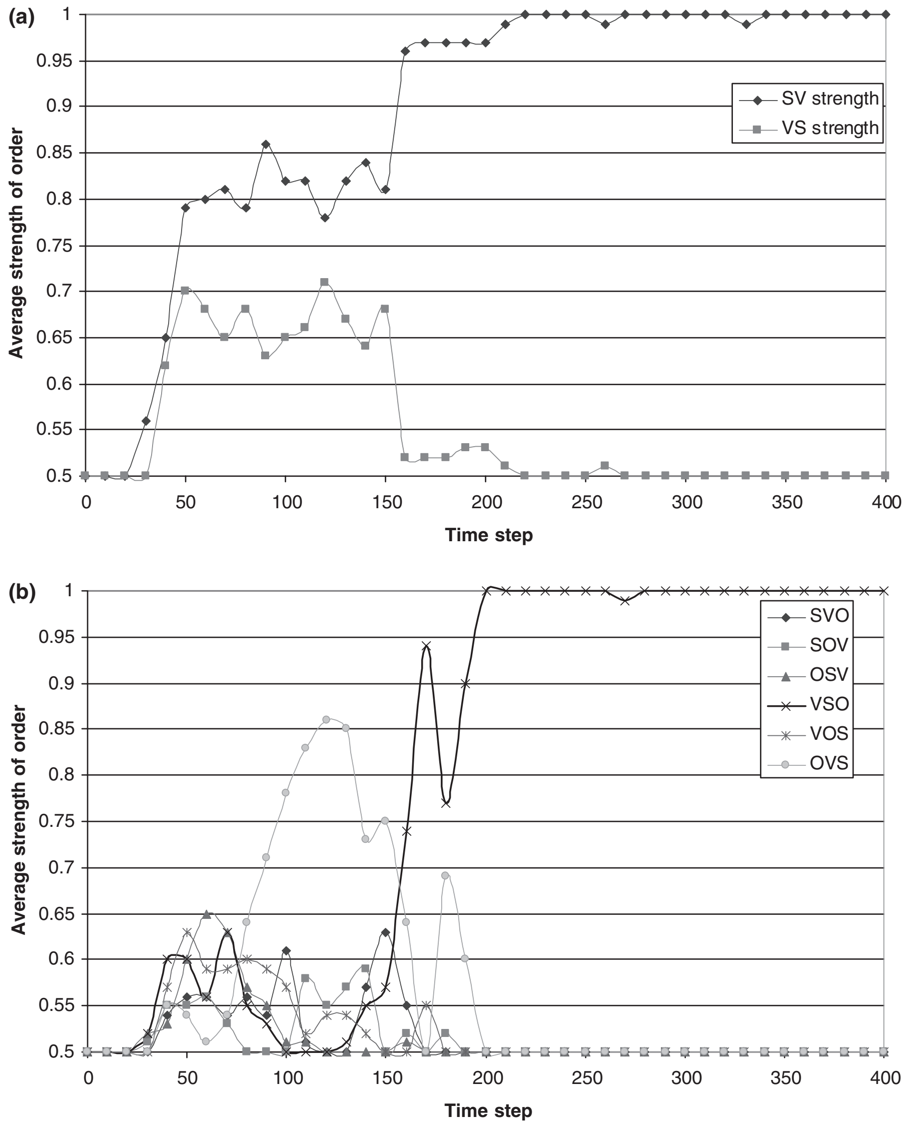

Figure 3: The emergence of dominant word orders for ***predicate<actor>*** *meanings and* ***predicate<actor, patient>*** *meanings*

internal linguistic representations actually differ in many ways. Table 1 shows the linguistic rules of two agents. Each agent has a set of word rules as well as a few holistic rules. The strengths of the rules are shown in parentheses after the rules. Despite the fact that both agents use VSO and SV as the dominant word orders (as shown in Figure 3) and share many words and phrases, they have several different word rules and holistic rules.

Table 1: The linguistic repertoire of two agents from a typical run

Agent 1: Individual word rules (13)	Agent 2: Individual word rules (13)
'chase'↔/8/(Str = 1.0)	'chase'↔/8/(Str = 1.0)
'drink'↔/15/(Str = 1.0)	'drink'↔/15/(Str = 1.0)
'eat'↔/25/(Str = 1.0)	'eat'↔/25/(Str = 1.0)
'fight'↔/19/(Str = 1.0)	'fight'↔/19/(Str = 1.0)
'run'↔/21/(Str = 1.0)	'run'↔/21/(Str = 0.27)
'sleep'↔/16/(Str = 1.0)	'run'↔/22/(Str = 1.0)
	'sleep'↔/16/(Str = 1.0)
'bear'↔/22/(Str = 1.0)	'bear'↔/22/(Str = 1.0)
'deer'↔/1/(Str = 1.0)	'deer'↔/1/(Str = 1.0)
'meat'↔/15/(Str = 1.0)	'meat'↔/16/(Str = 1.0)
'rabbit'↔/19/(Str = 1.0)	'rabbit'↔/19/(Str = 1.0)
'tiger'↔/8/(Str = 1.0)	'tiger'↔/8/(Str = 1.0)
'water'↔/16/(Str = 1.0)	'water'↔/18/(Str = 1.0)
'water'↔/18/((Str = 0.94)	
Holistic Rules (phrase or formulaic expression) (2)	Holistic Rules (phrase or formulaic expression) (3)
'chase < tiger, rabbit >'↔/16 8 18/(Str = 0.44)	'drink < bear, water >'↔/15 19 11/(Str = 0.28)
'fight < tiger, deer >'↔/15 19 16/(Str = 0.34)	'run < rabbit >'↔/19 1 22/(Str = 0.44)
	'sleep < tiger >'↔/19 22 1/(Str = 0.28)
Dominant word order rules	
SV for predicate < actor > meanings & VSO for predicate < actor, patient > meanings	

For example, the two agents have different forms of the meaning 'meat'. There are also homophones and synonyms, such as those seen in the natural languages. For example, agent 1 has a synonym pair for the meaning 'water', and agent 2 has a homophone pair 'meat' and 'sleep'.

In the above typical run, the final dominant word orders are SV and VSO. As the model has no built-in bias toward any order, it is expected that different orders will have the same probability as the final dominant order. In order to test this hypothesis, the model was run twenty times. It turned out that indeed different orders all occur with similar probabilities, as shown in Table 2. Note that the fact that SOV appears more frequently than others here is a coincidence, as the number of runs, twenty, is very small. Therefore we cannot make the claim that the model shows that SOV is the most basic

Table 2: The frequency of dominant word orders in 20 runs

SV	VS	SOV	SVO	OVS	OSV	VOS	VSO
10	10	5	3	4	2	3	3

word order, although studies of language change, including sign languages (e.g. Sandler *et al.* 2005) have suggested that this is the case.

Discussion of the model

The above are some preliminary results based on our basic model. There are many possible directions in which one could explore and ways in which one could refine the model. First of all, in the current model the population is constant, and there is no age difference among agents, and no learning of new agents is implemented. It is important to examine how the dynamics of emergence will change if children's learning and adults' interactions are modeled differently, and population flux, generation replacement, as well as different social structures, are taken into account. As Kirby (2002b) proposes, it is the bottleneck in the transmission across generations that promotes the emergence of a language with combinatorial and recursive structures. With more realistic configurations, the model could help to further explore this issue. In order to simulate the social environment at the time when language first evolved, we may need to take into account some archaeological or palaeo-demographical data, which has been largely ignored in the field of modeling so far (see Coupé and Hombert (2005) for an example in this direction).

More constraints on assumptions about the agents and the populations can be included in the model. For example, so far there is no built-in cognitive bias for sequencing words in order, and all possible orders emerge with equal probabilities. However, empirical studies have shown that SOV is more fundamental and may be the word order of the ancestor language of modern languages. It poses a challenge for the model to simulate this bias as an emergent phenomenon without building in the bias in the first place (see a recent attempt reported in Minett *et al.* 2006).

In the model, agents are homogeneous in their assumed capacities, such as creating new signals and extracting patterns with the same probability. This, however, may not be true in reality. Gong *et al.* (2005) have reported some results for a heterogeneous population, suggesting that a limited degree of heterogeneity in terms of storage capacities and linguistic abilities does not significantly affect the emergence of language. The robustness of language emergence in this model raises an interesting question about continuity: if there are continua between chimpanzees and humans in terms of shared cognitive capacities (e.g. symbolization, sequential ability, etc.), how great are the actual differences across the two species, compared to that within the humans? It is possible that the differences may not be dramatic in any of the capacities, but small quantitative differences may lead to qualitative differences, as an intrinsic feature of emergence in complex systems (Ke *et al.* 2006).

In addition to issues of refining and exploring the model in its implementations and parameters, the model raises questions for empirical studies of language acquisition as well. The recurrent pattern detection implemented in the model is relatively arbitrary: words are only extracted when they recur as patterns in more than one signal; after extracting the recurrent pattern, the remaining parts in the utterances are not analyzed; the pattern detection is exhaustive in trying to find as many patterns as possible. All these need to be verified against empirical studies. Controlled experiments may be needed to investigate details of the ways children detect patterns in the input speech signals from the environment.

In this model, we have implemented a homophony avoidance condition. That is, when an agent increases the strength of a word rule, he checks his rule list, and decreases those homophone words (words with the same form but different meanings) which are in the same semantic category as the word in question, but not the words in a different semantic category. For example, a listener has three rules, '*deer*' ↔/12 2/(0.5), '*rabbit*'↔/12 2/(0.4) and '*run*<#>'↔/12 2/(0.7), which are homophones. If, in a communication episode, the listener chooses the first rule and achieves a confident comprehension, then the strength of the second rule decreases, while the third one is not affected. Gong *et al.* (2005) show that without the homophone avoidance, the model will find it much harder to converge on a shared language with high mutual understanding. It is known that in the study of language acquisition, it has been hypothesized that children are born with a mutual exclusivity principle (Markman and Wachtel 1988), which results in synonym avoidance. But there has not been much research on how children handle homophones, and whether they avoid them. These questions are worthy of further empirical studies.

CONCLUSIONS: EMERGENTISM FOR LANGUAGE ORIGIN AND ITS IMPLICATIONS FOR APPLIED LINGUISTICS

This paper adopts an emergentist perspective for the study of language origin, which provides a more effective approach to addressing language origin than the nativist view which has dominated the field for decades. While nativism attempts to explain the origin of language by examining mostly the biological endowment in individuals, emergentism, by contrast, advocates examining the effect of long-term interactions between individual language users. Emergentism concentrates on the emergence of language at the population level. Research on biological explanations for language origin will benefit from this shift, by asking more pertinent questions about the initial conditions for language acquisition and language origin. These initial conditions are unlikely to be the highly abstract, innate mechanisms for syntax proposed by UG theorists, such as c-command or the subjacency principle, and so on, for which the universality in existence and representation are dubious. Instead, low-level mechanisms and capacities, such as intention detection, imitation, sequential abilities, analogy, and so on, may be more relevant. Although it is still unclear yet if these abilities are sufficient to account for a fully-fledged language, it is helpful to see what these simple capacities can lead to. While it is hard to examine the long-term effects of interactions in empirical studies, computer models provide an effective way of studying the actual emergent process in a controllable manner, and of examining the effects of variables and parameters. The agent-based model presented in this paper, as an illustration, demonstrates how a compositional language with simple word orders can emerge from a holistic signaling system, without changes in the agents' intrinsic properties.

The emergentist perspective adopted for the study of language origin shares a central idea with the study of language acquisition, which is that unexpected structures come into being spontaneously as a result of long-term interactions between components in the system, and the structures cannot be explained simply by examining the individual components. The emergence that language origin and language acquisition are concerned with, however, is at two different levels. Emergence in language acquisition takes place at the level of individual learners, as a result of the interactions between innate abilities in learners and their experiences in the environment. In contrast, language origin is emergent across a longer time span at the level of population, as a result of the interactions between different individuals in the speech community. Nevertheless, investigations of the two levels inform each other. As illustrated in this paper, the model of language origin makes use of findings from the study of language acquisition. In this way, the model shows how phylogeny can be studied by recapitulating ontogeny. At the same time, models of language origin raise questions for empirical study of language acquisition. In particular, during computer modeling, as every assumption has to be made explicit and implementable, specific questions arising from the design of models, such as whether decompositions happen when recurrent patterns are extracted from the input, how homophony is treated by children, and so on, will pose new research topics for psycholinguistic and corpus studies.

What contributions or insights could the study of language origin from an emergentist perspective provide for applied linguistics? First of all, the study of language origin addresses questions concerning the nature of human language and its defining characteristics. These intriguing questions would lead us to a bigger picture when we study and teach language. From an emergentist perspective, language is dynamic, perpetually evolving and constructed in a piece-meal manner, not only in the individual but also in the population. This will remind us of bearing a balanced view of language between its biological and cultural aspects. Then we may be more careful not to ascribe the observed regularities in language development too readily to learners' shared biological predispositions. We will look more closely at the contributing factors in the learning environment and the learning process.

Secondly, what has been highlighted in the emergentist view for language origin can find parallels in many current thoughts in the field of applied linguistics. For example, an agent's cognitive apparatus for learning and interaction is made very clear at the beginning of the model; this should find close connections with the studies of cognitive linguistics in first and second language acquisition, as well as the connectionist models which emphasize the use of general cognitive abilities for language learning. Interaction is the crucial source of emergence. In the model discussed in this paper, the agents construct their own languages through interactions with others. The input that agents receive therefore determines their language development. This is in line with the various input-based theories of SLA (e.g. Krashen 1985), and the current model can be extended to study the relation of input and the regularity of development. The social and cultural factors play crucial roles in the process of individual's learning, as has been recognized in the study of SLA (Lantolf 2000). Moreover, agents' language development in the model is similar to the interlanguage development studied in SLA, which is viewed as a dynamic construction process in its own right, instead of an unimportant intermediate transition toward a static target (Larsen-Freeman 1997). As learning is a self-constructing process, it is very important to raise learners' awareness and direct their attention to patterns in the learning input and also to their own errors. Tomasello and Herron (1988) have suggested a 'garden path' technique to lead learners to make errors and then learn from them. For example, to learn past tense in English, learners are first given the rule, which naturally results in overgeneralization, such as 'eated' for 'ate'. Once they make an error, and only after they have actually made an error, learners receive feedback on their errors. It is shown that this method is more effective than telling learners in advance about exceptions to a rule (cited in Larsen-Freeman 2003).

Thirdly, the highly interdisciplinary nature in the study of language origin may provide applied linguistics with insights into exploring new research methodologies and cross-discipline collaborations. Computer modeling may be one productive area to experiment. The computer model presented in this paper demonstrates how relevant assumptions and parameters can be explicitly considered, implemented, and varied. This research methodology should bring some new insights for SLA and applied linguistics, which often need to take into account a wide range of factors not only concerning the learners' cognitive abilities, but also the interactions between learners, the social and cultural factors, and the time and space dimension of the learning process. With the help of computer modeling, the effect of these complicated factors and their interactions can be properly explored.

The simple model presented in this paper highlights two important features of emergent phenomena: heterogeneity and nonlinearity. As we have seen from the model, even though the population as a whole can achieve a high mutual understanding between individuals, individuals' languages, that is the idiolects, differ from each other from the very beginning. In real life, children exhibit different growing patterns in their language development (Bates *et al*. 1995). These individual differences are even more prevalent in second language acquisition, not only in their observable linguistic behaviors in the process of learning (Larsen-Freeman, this issue), but also in cognitive mechanisms underlying language aptitude, motivation, learning styles, and so on (Dörnyei and Skehan 2003). Though the issue of 'learner variety' has long been recognized, there is not enough actual research and teaching practice yet (Larsen-Freeman 1998). It is necessary to recognize heterogeneity in learners at every stage of learning, and provide individually-based feedback as much as possible. Moreover, it is also helpful to highlight the heterogeneity in the target language to be learned. Learning is not trying to reach a static target language; instead, learners create a language by themselves in the process of learning (Larsen-Freeman 1997, 2003). It is important to highlight the fact that there is no single standard language to learn. Instead, language exists as a large variety of idiolects dependent on different genres, speech styles, social classes, etc. Therefore, it is important to raise students' awareness of not only the regularity, but also variation, and instability in actual language use. That will benefit their learning in the long run.

Another distinctive feature of emergent systems is the existence of nonlinearity and phase transitions. The dynamics of the system does not proceed in a linear way. Sometimes the system may go through sharp transitions with abrupt changes, even when there is no abrupt change in either the external input to the system or the internal parameters of the system. The agent-based model presented in this paper demonstrates this type of phase transition in the emergence of a dominant word order, as shown by the sharp growth in expressivity shown in Figure 2. In the process of language acquisition, there are many such sharp transitions. In order to be able to observe these transitions, we have to zoom in on the right time period and scrutinize the intermediate stages within that window. Otherwise, when this short time frame is missed, one observes the two plateau stages before and after the transition, and misses the rich characteristics in the transition period. Nonlinearity has two significant implications: (i) in order to understand how learning progresses, we have to pay special attention to capturing such abrupt transitions, and find out if there are particular conditions or prompts that trigger such transitions; (ii) we will expect plateau periods, and provide continuing support to learners even though at times there seems to be no significant progress.

To quote Larsen-Freeman (2003: 112), 'since language development process is nonlinear, interaction may be followed by more interaction with little obvious lasting change in learners' interlanguage. Then, one day, for any given learner, the penny will drop. All we can say for sure is that it is a very lucky teacher who is there to witness its happening.'

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NOTES

1 It is not impossible, however, for new syntactic structures to emerge within one generation, as reported in the recent studies on the development of two sign languages, one in Nicaragua (Senghas *et al*. 2004) and one in Israel (Sandler *et al*. 2005). Creole languages are also known for their rapid development within two or three generations (Mufwene 2001).

2 However, it has been found that the human brain has undergone rapid adaptive evolution after separating from other primates. In a recent issue of *Science* (2005, 309: 5741), two reports show that two genes (*Microcephalin* and ASPN) which regulate brain size, arose in the lineage of *homo sapiens* about 37,000 years and 5,000 years ago respectively. They have increased their frequency very rapidly in the species, indicating strong positive selection, although the exact nature of the selection force is still unclear.

3 Alternative terms for 'agent-based models' used in the literature include 'individual-based models' and 'multi-agent models'.

4 Journals such as *Adaptive Behavior, Artificial Life*, and *Interaction Studies*: *Social Behaviour and Communication in Biological and Artificial Systems* (which appeared as Evolution of Communication before 2004), among others, frequently publish reports on computer models of language origin. Updated information about publications and conferences in the field can be found in the *Language Evolution and Computation Bibliography* (http://www.isrl.uiuc.edu/~amag/langev/).

5 'Actor' is used to replace the traditional term for the semantic role 'agent', in order to avoid possible confusion with the term 'agent' used in 'agent-based model'.

6 The six pre-existing holistic signals are taken to simulate the innate communicative signals found in other animals, such as the vervet monkey's alarm calls.

REFERENCES

Akhtar, N. 1999. 'Acquiring basic word order: Evidence for data-driven learning of syntactic structure,' *Journal of Child Language* 26: 339–56.

Batali, J. 1998. 'Computational simulations of the emergence of grammar' in J. R. Hurford, M. Studdert-Kennedy, and C. Knight (eds): *Approaches to the Evolution of Language: Social and Cognitive Bases*. Cambridge; New York: Cambridge University Press, pp. 405–26.

Bates, E., P. Dale, and **D. Thal.** 1995. 'Individual differences and their implications for theories of language development' in P. Fletcher and B. MacWhinney (eds): *Handbook of Child Language*. Oxford: Basil Blackwell, pp. 96–151.

Briscoe, E. J. 2002. 'Grammatical acquisition and linguistic selection' in E. J. Briscoe (ed.): *Linguistic Evolution through Language Acquisition: Formal and Computational Models*. Cambridge; New York: Cambridge University Press, pp. 255–300.

Camazine, S., J.-L. Deneubourg, N. Franks, J. Sneyd, G. Theraulaz, and **E. Bonabeau** (eds). 2001. *Self-Organization in Biological Systems*. Princeton, NJ: Princeton University Press.

Cann, R. L., M. Stoneking and **A. C. Wilson** 1987. 'Mitochondrial DNA and human evolution,' *Nature* 325: 31–6.

Cangelosi, A. and **S. Harnad**. 2000. 'The adaptive advantage of symbolic theft over sensorimotor toil: Grounding language in perceptual categories,' *Evolution of Communication* 4/1: 117–42.

Cangelosi, A. and **D. Parisi**. (eds) 2001. *Simulating the Evolution of Language*. London: Springer-Verlag.

Cavalli-Sforza, L. L. 1997. 'Genes, peoples, and languages,' *Proceedings of the National Academy of Sciences, U. S. A*. 94/15: 7719–24.

Christiansen, M. 1994. Infinite languages, finite minds: connectionism, learning and linguistics structures. Unpublished Ph.D. dissertation, University of Edinburgh.

Christiansen, M. H. and **S. Kirby**. (eds) 2003. *Language Evolution*. Oxford: Oxford University Press.

Conway, C. M. and **M. H. Christiansen**. 2001. 'Sequential learning in non-human primates,' *Trends in Cognitive Sciences* 5: 539–46.

Coupé, C. and **J. M. Hombert.** 2005. 'Polygenesis of linguistic strategies: A scenario for the emergence of language' in J. Minett and W. S.-Y. Wang (eds): *Language Acquisition, Change and Emergence: Essays in Evolutionary Linguistics*. Hong Kong: City University of Hong Kong Press.

Davidson, I. and **W. Noble**. 1992. 'Why the first colonisation of the Australian region is the earliest evidence of modern human behaviour,' *Archaeology in Oceania* 27: 135–42.

Deacon, T. 1997. *The Symbolic Species*. New York: W. Norton and Co.

de Boer, B. 2001. *The Origins of Vowel Systems*. Oxford: Oxford University Press.

de Waal, F. B. M. 2005. 'A century of getting to know the chimpanzee,' *Nature* 437/7055: 56–9.

Dörnyei, Z. and **P. Skehan.** 2003. 'Individual differences in second language learning' in C. J. Doughty and M. H. Long (eds): *Handbook of Second Language Acquisition*. Malden, MA: Blackwell, pp. 589–630.

Ellis, N. C. 1998. 'Emergentism, connectionism and language learning,' *Language Learning* 48: 631–64.

Elman, J., E. Bates, M. H. Johnson, A. Karmiloff-Smith, D. Parisi, and **K. Plunkett** (eds). 1998. *Rethinking Innateness—A Connectionist Perspective on Development*. Bradfork Book/MIT Press.

Gong, T., J.-Y. Ke, J. W. Minett, and **W. S.-Y. Wang.** 2004. 'A Computational Framework to Simulate the Co-evolution of Language and Social Structure.' *Proceedings of ALife 9,* Boston, MA.

Gong, T., J. A. Minett, J.-Y. Ke, J. H. Holland and **W. S.-Y. Wang.** 2005. 'Coevolution of lexicon and syntax from a simulation perspective,' *Complexity* 10/6: 1–13.

Hauser, M. and **W. T. Fitch.** 2003. 'What are the uniquely human components of the language faculty?' in M. H. Christiansen and S. Kirby (eds): *Language Evolution*. Oxford: Oxford University Press.

Hauser, M. D., N. Chomsky, and **W. T. Fitch.** 2002. 'The faculty of language: What is it, who has it, and how did it evolve?' *Science* 298: 1569–79.

Hawkins, J. A. and **M. Gell-Mann**. (eds) 1992. *The Evolution of Human Languages*. Reading, MA: Addison-Wesley.

Holland, J. H. 1998. *Emergence: From Chaos to Order*. Reading, MA: Addison-Wesley.

Hopper, P. J. and **E. C. Traugott.** 1993. *Grammaticalization*. Cambridge, New York: Cambridge University Press.

Hurford, J. R., M. Studdert-Kennedy, and **C. Knight** (eds). 1998. *Approaches to the Evolution* *of Language*. Cambridge, New York: Cambridge University Press.

Jackendoff, R. 1999. 'Possible stages in the evolution of the language capacity,' *Trends in Cognitive Sciences* 3/7: 272–9.

Kauffman, S. A. 1995. *At Home in the Universe*. Oxford: Oxford University Press.

Ke, J.-Y. 2004. Self-organization and language evolution: system, population and individual. unpublished Ph.D. dissertation, Hong Kong: City University of Hong Kong.

Ke, J.-Y., C. Coupé, and **T. Gong.** 2006. 'A little bit more, a lot better—language emergence from quantitative to qualitative change' in A. Cangelosi, A. D. M. Smith, and K. Smith (eds): *The Evolution of Language*, Singapore: World Scientific Publishing Co. Pte. Ltd., pp. 419–20.

Ke, J.-Y., C. P. Au, J. W. Minett, and **W. S.-Y. Wang.** 2002. 'Self-organization and selection in the emergence of vocabulary,' *Complexity* 7/3: 41–54.

Kirby, S. 2000. 'Syntax without natural selection: How compositionality emerges from vocabulary in a population of learners' in C. Knight, J. R. Hurford, and M. Studdert-Kennedy (eds): *The Evolutionary Emergence of Language: Social Function and the Origins of Linguistic Form*. Cambridge; New York: Cambridge University Press, pp. 303–23.

Kirby, S. 2002a. 'Natural language from artificial life,' *Artificial Life* 8/2: 185–215.

Kirby, S. 2002b. 'Learning, bottlenecks and the evolution of recursive syntax' in E. J. Briscoe (ed.): *Linguistic Evolution through Language Acquisition: Formal and Computational Models*. Cambridge, New York: Cambridge University Press, pp. 173–205.

Klein, R. 1999. *The Human Career: Human Biological and Cultural Origins* 2nd edn. Chicago: University of Chicago Press.

Knight, C., J. Hurford, and **M. Studdert-Kennedy** (eds). 2000. *The Evolutionary Emergence of Language: Social Function and the Origins of Linguistic Form*. Cambridge, New York: Cambridge University Press.

Krashen, S. 1985. *The Input Hypothesis: Issues and Implications*. Harlow: Longman.

Lantolf, J. P. 2000. *Sociocultural Theory and Second Language Learning.* Oxford: Oxford University Press.

Larsen-Freeman, D. 1997. 'Chaos/complexity science and second language acquisition,' *Applied Linguistics* 18/2: 141–65.

Larsen-Freeman, D. 1998. 'On the scope of second language acquisition research: ''The Learner Variety'' perspective and beyond—A response to Klein,' *Language Learning* 48: 551–6.

Larsen-Freeman, D. 2003. *Teaching Language: From Grammar to Grammaring*. Boston: Thomson/Heinle.

Lieven, E. V. M., J. M. Pine, and **G. Baldwin.** 1997. 'Lexically-based learning and early grammatical development,' *Journal of Child Language* 24/1: 187–219.

MacWhinney, B. (ed.) 1999. *The Emergence of Language*. Mahwah, NJ: Lawrence Erlbaum Associates.

MacWhinney, B. 2002. 'The competition model: the input, the context, and the brain' in P. Robinson (eds): *Cognition and Second Language Instruction*. Cambridge, New York: Cambridge University Press.

Markman, E. M. and **G. F. Wachtel.** 1988. 'Children's use of mutual exclusivity to constrain the meaning of words,' *Cognitive Psychology* 20: 121–57.

Meltzoff, A. N. 1996. 'The human infant as imitative generalist: A 20-year progress report on infant imitation with implications for comparative psychology' in C. M. Heyes and B. G. Galef (eds): *Social Learning in Animals: The Roots of Culture*. Academia Press, pp. 347–70.

Milroy, L. 1987. *Language and Social Networks*. Oxford, New York: Blackwell.

Minett, J. W. and **W. S.-Y. Wang** (eds). 2005. *Language Acquisition, Change and Emergence: Essays in Evolutionary Linguistics*. Hong Kong: City University of Hong Kong Press.

Minett, J. W., T. Gong, and **W. S.-Y. Wang.** 2006. 'A language emergence model predicts word order bias' in A. Cangelosi, A. D. M. Smith, and K. Smith (eds): *The Evolution of Language*, Singapore: World Scientific Publishing Co. Pte. Ltd., pp. 206–13.

Mufwene, S. S. 2001. *The Ecology of Language Evolution*. Cambridge, New York: Cambridge University Press.

Munroe, S. and **A. Cangelosi.** 2002. 'Learning and the evolution of language: The role of cultural variation and learning cost in the Baldwin Effect,' *Artificial Life* 8: 311–39.

Nettle, D. 1999. *Linguistic Diversity*. Oxford: Oxford University Press.

Nowak, M. A., **N. L. Komarova**, and **P. Niyogi**. 2001. 'The evolution of universal grammar,' *Science* 291:114–18.

Oudeyer, P.-Y. 2002. 'Phonemic coding might result from sensory-motor coupling dynamics,' *Proceedings of the 7th International Conference on the Simulation of Adaptive Behavior*, Edinburgh.

Pinker, S. and **P. Bloom.** 1990. 'Natural language and natural selection,' *Behavioral and Brain Sciences* 13: 707–84.

Pinker, S. and **R. Jackendoff.** 2005. 'The faculty of language: What's special about it?' *Cognition* 95/2: 201–36.

Sandler, W., I. Meir, C. Padden, and **M. Aronoff.** 2005. 'The emergence of grammar in a new sign language,' *Proceedings of the National Academy of Sciences, USA* 102/7: 2661–5.

Schumann, J. and **N. Lee.** 2005. 'Neurobiological and evolutionary bases for child language acquisition abilities,' *The 14th World Congress of Applied Linguistics (AILA 2005)*. Madison, Wisconsin, 24–29 July.

Senghas, A., S. Kita, and **A. Ozyurek.** 2004. 'Children creating core properties of language: evidence from an emerging sign language in Nicaragua,' *Science* 305: 1779–82.

Stam, J. H. 1976. *Inquiries into the Origin of Language: the Fate of a Question*. New York: Harper & Row.

Steels, L. 1996. 'A self-organizing spatial vocabulary,' *Artificial Life Journal* 2/3: 319–332.

Steels, L. and **F. Kaplan.** 2002. 'Bootstrapping grounded word semantics' in E. J. Briscoe (ed.): *Linguistic Evolution through Language Acquisition: Formal and Computational Models*. Cambridge, New York: Cambridge University Press, pp. 53–73.

Terrace, H. S. 2002. 'Serial expertise and the evolution of language' in A. Wray and F. J. Newmeyer (eds): *The Transition to Language*. Oxford: Oxford University Press, pp. 64–90.

Thompson, R., J. K. Pritchard, P. Shen, P. J. Oefner, and **M. W. Feldman.** 2000. 'Recent common ancestry of human Y chromosomes: evidence from DNA sequence data,' *Proceedings of the National Academy of Sciences, USA* 97: 7360–5.

Tomasello, M. 2003. *Constructing a Language: A Usage-based Theory of Language Acquisition*. Cambridge, MA: Harvard University Press.

Tomasello, M. and **C. Herron.** 1988. 'Down the garden path: Inducing and correcting overgeneralization errors in the foreign language classroom,' *Applied Psycholinguistics* 9: 237–46.

Tomasello, M., N. Akhtar, K. Dodson, and **L. Rekau.** 1997. 'Differential productivity in young children's use of nouns and verbs,' *Journal of Child Language* 24: 373–87.

Wagner, K., J. A. Reggia, J. Uriagereka, and **G. S. Wilkinson.** 2003. 'Progress in the simulation of emergent communication and language,' *Adaptive Behavior* 111: 37–69.

Wang, W. S.-Y., J.-Y. Ke, and **J. W. Minett.** 2004. 'Computer modeling of language evolution' in C.-R. Huang and W. Lenders (eds): *Computer Linguistics and Beyond: Perspectives at the Beginning of the 21st Century*. Taipei: Language and Linguistics, Academia Sinica.

White, T. D., B. Asfaw, D. DeGusta, H. Gilbert, G. D. Richards, G. Suwa, and **F. C. Howell.** 2003. 'Pleistocene homo sapiens from middle Awash, Ethiopia,' *Nature* 423: 742–7.

Wray, A. (ed.) 2002a. *The Transition to Language*. Oxford: Oxford University Press.

Wray, A. 2002b. *Formulaic Language and the Lexicon*. Cambridge; New York: Cambridge University Press.