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The Evolution of Language

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1. Introduction: language and the evolution of life

Maynard Smith & Szathmáry (1997) set out 8 "major transitions" in the evolution of life. These are events in the history of our planet that signal radical changes in the way evolution works. They start with a change in the way molecules replicate in the very earliest stages of the origins of life, through the emergence of DNA, and go on to include larger-scale later phenomena like the evolution of colonies where once there were only solitary individuals (see figure 1). What makes the work of these two eminent evolutionary biologists so interesting for us is their inclusion of the most recent evolutionary transition: the emergence of language.

Why is the emergence of language such a significant event? What does it have in common with the other major evolutionary transitions? One of Maynard Smith & Szathmáry's interesting observations is that, despite their diversity, these transitions have some features in common. In particular, many of the transitions give rise to a new mechanism for the transmission of information. Language, they argue, provides just such a novel mechanism - essentially enabling a system of cultural transmission with unlimited heredity.

It is clearly true that language enables the transmission and storage of very complex cultural information. Arguably, it is this aspect of our biological heritage that makes our species impact so great, and so unusual. But how does human language achieve this? To answer this question, it is worth briefly surveying the structural features of language, and the characteristics of language as a biological endowment.

Replicating molecules → Populations of molecules
Independent replicators → Chromosomes
RNA → DNA
Prokaryotes → Eukaryotes
Asexual clones → Sexual populations
Protists → Animals, plants, fungi
Solitary individuals → Colonies
Primate societies → Human societies, **Language**

Figure 1*: Maynard Smith & Szathmáry's (1997) eight major transitions in the evolution of life.*

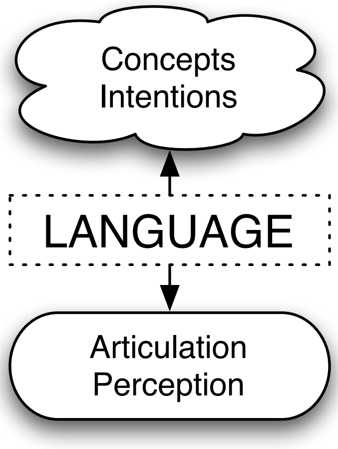

***Figure 2**: Language as a system mapping between concepts/intentions and perception/articulation*

The structure of language

One way of thinking about language (although by no means the only way, e.g. Origgi & Sperber 2000) is as a coding system that maps between two spaces: the space of concepts and intentions on the one hand, and of articulation and perception on the other (see figure 2). Traditionally, the study of the structure of language has been divided into a number of sub-disciplines, each of which tackles a different aspect of this mapping system:

- **Phonetics**: the production and perception of sounds / manual gestures
- **Phonology**: the systematic behaviour of the sounds of language
- **Morphosyntax**: the system for combining the basic meaningful units of language into words and sentences[1]
- **Semantics**: the meaning of words and sentences in isolation
- **Pragmatics**: the system for relating word / sentence meaning to communicative intention in the context of communication

The first and last two areas on this list deal in the main with the two ends of the mapping in figure 2, whereas morphosyntax is most clearly the study of the aspects of language that govern how these two are connected. In one influential view of how language works, syntax is the study of the computational system that accesses our mental lexicon and bridges the gap between the conceptual-intentional and articulatory-perceptual "interfaces" (Chomsky 1995).

What's extraordinary about this system, and what makes it particularly important for Maynard Smith & Szathmáry, is that it is constructed in such a way as to allow unbounded yet faithful transmission of information (sometimes termed "digital infinity"). This combination of an infinite range of messages with a high-fidelity mechanism for transmitting those messages is almost unique in nature. Arguably the only other example is the genetic code itself.

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[1] Sometimes this is divided into Morphology and Syntax, dealing with the below-word and above-word level respectively. Equally, linguistics sometimes use "syntax" to refer to morphosyntax as I will do in this chapter.

It is easy to see why human language is in principle unbounded. If we were to try and find the longest sentence of English, we would fail. This is because the syntactic system delivers us mechanisms that will allow us to elaborate on sentences in an unlimited fashion (e.g. by adding subordinate clauses, adverbial phrases, prepositional phrases etc. etc.). This kind of infinity is "digital" because it does not rely on continuous changes in the signal to convey changes in meaning but rather the addition of discrete elements. In contrast, we could imagine a different signalling system where the pitch of a signal conveyed differences in meaning (say, the severity of a particular threat). This system would be infinite, since there are infinitely many different pitches, but it would not be digital.

Another unusual aspect of human language is that the lexicon is flexible. New words can be added, and the meanings of words can change. Although this feature of language is not discussed as much as digital infinity, it is actually the combination of these two that really set human language apart as a uniquely powerful tool for the unbounded transmission of cultural information. In summary, language structure allows high-fidelity, unbounded and flexible communication.

Language as a biological endowment

Language structure is unusual and unusually powerful, so how do we come to have this system? Obviously, language is at least in part a learned behaviour. Languages differ from each other, and these differences have no obvious correlations with genetic differences in their speakers. Language variation is primarily a hallmark of those aspects of language that are learned. This is most obvious in the lexicon, which varies in a largely arbitrary way from language to language (although historically related languages will have more or less similar lexica, and this can be used to trace language history). Indeed, the fact that the words of a language are learned is what enables the flexibility of expression mentioned in the previous paragraph.

The lexicon is not the sole locus of variation in language, however. The phonological structure of languages varies, as does their syntax. That said, this variation seems to be constrained in various ways. In other words, there exist certain language universals that become obvious when a large number of languages are examined, or when historically distant languages are compared in detail. It is a matter of controversy what these constraints on variation indicate - for example, they could reflect those aspects of language that are not learned (i.e. that are innate), or they could result from universal properties of the way language is used (Kirby 1999; Newmeyer 1998).

In any case, however much of language is learned it is clear that language is both enabled and constrained by our biology, and much research in linguistics is aimed at characterising what this biological endowment is. Whatever the final definitive account of this is (and we are some way off anything approaching consensus), we can expect it to include neurological systems for the acquisition of language, the representation of linguistic knowledge, and the rapid on-line processing of language, as well as physical apparatus for the production of speech.

Evolutionary questions

The emergence of language is an important evolutionary event, and arguably our species' defining characteristic, but how exactly *did* it evolve? Questions surrounding the origins and evolution of language have, since the early nineties, seen a huge explosion of interest in the scientific community, across a very wide range of disciplines. In the remainder of this chapter, I will try and give a flavour of the work that is going on by surveying three different areas of interest. It is important to realise that this is very far indeed from being an exhaustive summary of a subject that draws on evidence from archaeology to computer science, from genetics to philosophy. The interested reader is encouraged to look at a survey of field such as Christiansen & Kirby (2004) or the series of books arising from the biennial conference series on Language Evolution (Hurford et al. 1998; Knight et al. 2000; Wray 2002; Tallerman 2005).

Before diving into the subject, however, it is worth reflecting on the sorts of questions that researchers are, often implicitly, trying to answer. It may be that some confusion in debates in the field actually arises from the fact that different questions are being asked. These can be roughly characterised as follows:[2]

- **Structure**: Why is language the way it is and not some other way? How can an evolutionary approach explain the particular language universals we observe?
- **Uniqueness**: Why are we unique in possessing language? What is so special about humans?
- **Function**: How could language evolve? What were the selective pressures involved?
- **History**: What is the evolutionary story for language? When did it evolve? Were there intermediate stages?

2. Language and Human Uniqueness: the comparative approach

The first of the three areas we'll survey is in some sense a methodological one although it relates to the **structure** and **uniqueness** questions above. It is surprisingly controversial and it goes to the heart of what we mean when we talk about human language and human uniqueness.

It is probably fair to say that linguists have traditionally stressed the distinctiveness of human language as compared to other communication systems in the natural world. Communication is very much the norm among almost all species on the planet, whether it be between animals, insects, plants or bacteria, but language is normally considered to be something very different. Indeed, humans also have communication systems that aren't language, that seem to share many similarities with communication in other species. So, for example, we do not consider the various vocalisations like screaming, laughter or crying to be linguistic, but they are arguably communicative.

It is natural, and reasonable, for linguistics as a field to see language as a unique phenomenon and set out the properties of human language that makes it special (see, for example, Hockett 1960 for an early attempt to set out language's *design features*). The problem with this stance from an evolutionary point of view is that it downplays what we can learn about language by looking at other species. If language is a one-off phenomenon - an *autapomorphy* - then how can we apply the standard methodologies from evolutionary biology?

Dividing the language faculty

A fairly recent development in the field suggests that we are moving beyond this point of view. In a paper in *Science* in 2002, two biologists joined forces with one of the architects of modern linguistic theory to focus on the relevance of data from other species to our understanding of human language and its evolution (Hauser, Chomsky & Fitch, 2002). They argue that many of the problems in discussions of language in its evolutionary context may arise from treating the language faculty as a unitary whole. As an alternative, they propose two different senses of the term biological language faculty: the faculty of language in the broad sense (FLB), and faculty of language in the narrow sense (FLN). The former includes all aspects of the language faculty, including conceptual-

[2] Note that it is tempting to compare these questions with Tinbergen's (1963) four famous evolutionary *why* questions. However, in contrast I mean these to reflect the kinds of questions that get posed in the literature on language evolution and some are clearly specific to language evolution (e.g. the **uniqueness** question).

intentional apparatus, perceptual-articulatory apparatus and so on. The latter includes only the core computational systems that govern the system of mapping in figure 2. More specifically, Hauser, Chomsky & Fitch (2002) put forward the strong hypothesis that FLN is essentially limited to a mechanism implementing *recursion*, which gives rise to the digital infinity mentioned earlier (see figure 3).

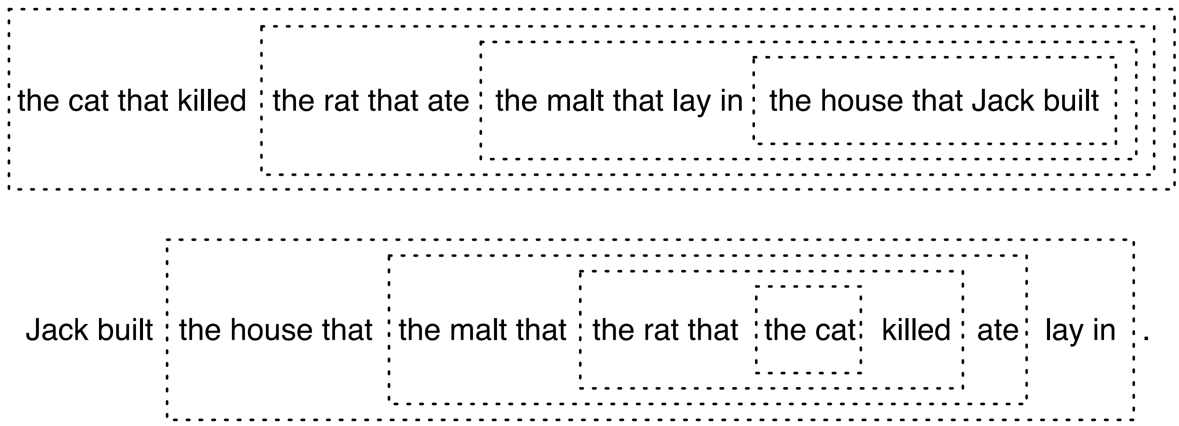

Figure 3*: Recursion in English. Noun-phrases can be recursively embedded within one another using the relative clause construction in English (boxes mark the boundaries of each noun-phrase in this figure). Recursion allows us to create sentences of potentially unlimited complexity, although in some cases the result can be difficult for us to process, such as when centre-embedding is overused (as in the lower of the two examples).*

Having made this distinction between a broad and narrow sense of the term, Hauser, Chomsky & Fitch (2002) set out three logically possible hypotheses about the evolution of the faculty of language:

1. FLB is homologous to animal communication. All aspects of FLB (including FLN) can be found relatively unchanged in animals.
2. FLB is a derived, uniquely human adaptation to language.
3. Only FLN is uniquely human.

Discovering which of these hypotheses is correct requires a collaboration between linguists and comparative biologists to determine how the language faculty (in the broad sense) can be divided up, and which aspects of the language faculty are shared with other species.

Hauser, Chomsky & Fitch (2002) argue that the comparative data points to only FLN being uniquely human. In other words, all aspects of the language faculty excepting the recursive system of mapping can be found in other species. For example, consider the system we have for acquiring complex signals - a crucial aspect of FLB. It turns out that there are analogs of this in a number of other species who have a capacity for vocal learning: song-birds, parrots, hummingbirds, bats, cetaceans (Jarvis 2004), a list to which have recently been added seals (Van Parijs et al 2003), elephants (Poole et al 2005) and possibly even mice (Holy 2005).

What about recursion - how can we test if other species have this computational ability? One approach is to use *artificial grammar learning* to probe the ability of different species to learn and process languages with different computational properties. Fitch & Hauser (2004) compare cotton-top tamarins and humans on a task with languages that differ in their requirement for recursion. Their results suggest that the difference between these two species does indeed hinge on a recursive capacity.

This approach, which puts forward a minimal account of human uniqueness, is not without its critics. For example, Pinker & Jackendoff (2005) argue that there is much more that is special to language and to humans than merely the capacity for recursion. Their arguments are of two main types. Firstly, they suggest that there are non-syntactic aspects of language that are uniquely human. For example, for them the huge size and rapid acquisition of the lexicon strongly suggests that this is a uniquely human adaptation. There is little evidence that any other species can acquire words in the same way children do, sometimes with only a single exposure.[3]

A second criticism that Pinker & Jackendoff (2005) have is that treating FLN as containing simply a mechanism for recursive computation oversimplifies the syntactic aspects of human language. Their view treats the syntactic system as a complex adaptation to the problem of "communicating propositional structures through a serial interface" (Pinker & Bloom 1990) - an adaptation consisting of many interacting sub-systems. The arguments for and against a *minimalist* view of syntax are well beyond the scope of this chapter (see Parker 2006 for an extended discussion), but what is interesting is how these specifically linguistic arguments are increasingly being informed by evolutionary thinking and comparative data.

The debate over the nature and uniqueness of FLN continues, and interested readers can also look at Fitch, Hauser & Chomsky's (2005) reply to Pinker & Jackendoff (2005), and even Jackendoff & Pinker's (2005) further response to this reply.

The descended larynx

One area where the comparative approach has had a substantial impact is in our understanding of the evolution of the vocal tract. Lieberman et al (1969) note an unusual feature of human vocal tract that appears to set it apart from the primate norm. Our larynx is positioned rather low in the throat (if you are a man, you will be able to find its position by feeling on your neck for your Adam's apple). This is puzzling because it means that we must coordinate breathing and swallowing carefully to avoid choking. If our larynx was higher, as it is in other mammals and in human infants, then it could be projected into the nasal cavity allowing us to breathe and swallow at the same time.

Lieberman (1969) suggests that this apparently counter-functional trait in humans is actually the result of an adaptation to communication. The descent of the larynx over our evolutionary history radically changed the shape of the vocal tract from one which essentially had the acoustic properties of a straight tube to one where that tube has a bend in the middle (where the oral cavity meets the pharynx). What this does is increase the diversity of vowel sounds that we can produce, which in turn increases the informational carrying capacity of the vocal channel.

More recently, Fitch & Reby (2001) have shown that there are other possible adaptive advantages to a descended larynx by looking carefully at the comparative data. It turns out that other mammals actually *do* lower their larynxes during vocalisation, and indeed some species (such as red deer) have a permanently lowered larynx in the male of the species. These animals certainly do not have complex vocal communication that requires the enhanced carrying capacity of a vocal tract with a bend in it, so what is going on?

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[3] Although there is intriguing experimental evidence that domestic dogs actually may be able to learn a large number of words by employing a *mutual exclusivity* bias that is argued to have very close parallels in child language acquisition (Kaminski et al 2004).

What lowering the larynx does in addition to creating a bend in the vocal tract is increase the total length of the tract. This changes the acoustic properties of vocalisations in such a way as to *increase the perceived size of the animal making the sound*. Fitch (2000) suggests that it is this perceived-size enhancement that is the driving force behind the descent of the larynx in species without complex vocalisations. Animals, particularly males, that appear to be large may be more successful in competition for mates, and in avoiding predation. If this is the case, then might it not also be a factor in the evolution of the human vocal tract? Certainly, even in humans there is some sexual dimorphism, with the male larynx undergoing a second descent around puberty.

What this example demonstrates is the role that evidence from other species can play in understanding the evolution of language, even if those species do not necessarily possess anything like a capacity for complex communication.

3. Protolanguage: living fossils and intermediate stages

Setting aside for a moment the language *faculty* and looking at the structure of language itself, it is clear that there is a huge gulf between the communication systems of our nearest primate relatives and human language. How was that gulf bridged by evolution? Did we move in one step from a largely innate, limited and fixed repertoire of unstructured signals to the open ended syntactic system that we have now? Or can we envisage a gradual process involving intermediate stages? The question "what good is half an eye?" is a familiar sceptical response to adaptationism, suggesting that something as complex as an eye could not have evolved gradually. A similar question might be "what good is half a language?". A gradual story for the evolution of the eye is possible because it turns out that there are "intermediate" eyes that are indeed useful and there is a plausible evolutionary trajectory from these intermediate forms to the modern eye. The study of *protolanguage* aims to demonstrate that the same is true for language.[4]

Bickerton's protolanguage

One of the difficulties for evolutionary linguists is that language does not fossilise. Although we are able to infer some things from the skeletal remains of our hominid ancestors it is hard to find *direct* evidence of the form of evolutionarily primitive language. Instead, Bickerton (1990; 1995) proposes that we look for *living fossils*. These are types of communication used by modern humans that are close to, but do not share all the features of, fully-modern language. Finding such living fossils demonstrates that there are possible intermediate stages, and providing we can find a plausible evolutionary trajectory that will take us from this protolanguage to full human language gives us a potential answer to the **history** question posed in section 1.

Bickerton (1995, appendix A) gives examples of three kinds of linguistic behaviour that, he says, constitute living fossils of protolanguage:

- **Pidgin communication.** This is the type of communication system, typically formed in slave plantations, where adults with diverse linguistic backgrounds are brought together and must negotiate a *lingua franca.* These examples are from Pidgin Hawaiian in the late 18th and early 19th century:

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[4] Of course, it may be true that language *did* emerge in one step, that a *saltational* view is a possible alternative to *gradualism*. This is only really plausible if language isn't as complex as it appears. (The appearance of eyes fully formed in evolution in one step is implausible precisely because the eye is a complex organ.) One of the consequences of Chomsky's minimalist approach to language is that they may be no need to posit intermediate stages (Berwick 1998). As noted in the previous section, this whole issue is a matter of considerable ongoing debate, however.

- Nuinui pool. Make kanaka. (Much-much gun. Kill men.)
- Maitai, nana Amerita. (Good, see America.)
- Apopo tabu. Aole hanahana. (Tomorrow forbidden. Not work.)
- Maitai, nuinui maitai. (Good, much-much good.)

▸ **Child language.** These examples are from one 23 month-old boy.

- Fix it.
- Tear up.
- More doggie.
- Door shut.

▸ **Language of trained apes.** These examples are from Koko, a language-trained Gorilla:

- That cat.
- More pour.
- Me good.
- Koko purse.

What do these have in common? They all have some minimal structure in that sentences are made of words which have distinct meanings and the meaning of the whole sentence is in some way composed of those word-meanings. However, this is very far from the systematic syntactic structure of "full human language". Note the following features of language that are missing: recursive embedding leading to indefinitely long sentences; propositional structure based on a verb and arguments which are optional only if their meaning is recoverable; grammatical elements (such as agreement markers, conjunctions, case-endings etc.) that do not directly correspond to aspects of the meaning of a sentence, but rather have purely structural roles.

Could this type of protolanguage constitute an evolutionarily early stage in the evolution of full human language? If so, then we are at least one step towards bridging the gulf between no-language and the syntactically-structured linguistic system that is our species defining characteristic. Note that protolanguage, like an intermediate eye, is *functional*. It can be used to communicate. An adaptationist programme for human language, such as Pinker & Bloom's (1990) which stresses communication as the adaptive function of language, is strengthened if such functional intermediates can be found.

Holistic protolanguage

Bickerton's is not the only proposal, however. Jackendoff (1999), for example, has suggested a greatly elaborated sequence of potential intermediate stages each of which implies a different protolanguage (although one of these is Bickerton's). A rather different perspective is set out by Wray (1998) as an alternative to the multi-word syntax-free intermediate stage. Like Bickerton, Wray seeks a living fossil - a qualitatively different kind of language that lacks the complexity normally associated with human syntax. She focusses on certain sequences in normal discourse whose structure appears to be essentially unanalysed in language production and perception: *holistic* language.

Whereas we normally think of the meanings of utterances being composed by combination of meaningful words, this is not always the case. Holistic *formulae* can be found in everyday language use most obviously in idiomatic expressions such as *bought the farm* (whose meaning, *died*, appears to be arbitrarily related to its form). Wray (1998) suggests other holistically processed expressions include adjuncts (*by and large*), collocations (*pure coincidence*, but never *true coincidence*), sentence frames (*NP be-TENSE sorry to keep-TENSE you waiting*), and standard situational utterances (*Was there anything else?*).

The existence of these formulae, which form a large proportion of our day-to-day language use, demonstrates that we are predisposed to store and manipulate unanalysed chunks of language despite also possessing syntactic mechanisms that could deliver purely compositional expressions by rule whenever needed. For Wray, it is reasonable to suppose that there existed a stage where we spoke a purely holistic protolanguage. Rather than building utterances through the combination of small numbers of referential words as Bickerton's protolanguage does, this holistic communication system would simply consist of a store of expressions each with a conventionalised meaning and stood alone as a complete utterance.[5]

The process of transition

One crucial difference that separates these two views of what protolanguage was like is the different process of transition proposed that takes us from protolanguage to full human language.

For Bickerton, the transition between these two forms of language was a biological one. Some genetic change or changes led to a novel language faculty that enabled individual language users to go beyond their cultural heritage (a syntax-free protolanguage) and innovate a modern language. Exactly how this change in the linguistic system would progress cannot be known for sure, but we might see parallels in the process of *creolisation* whereby children innovate a full human language after exposure to a pidgin.

Wray on the other hand sketches in some detail exactly how a holistic protolanguage might be transformed into full human language through a process of *fractionation* of the language by generations of language users. Correspondences between signals and meanings that arise by chance in the repertoire of holistic expressions are analysed by language learners who eventually generalise these analyses systematically to novel utterances. Kirby (2000) has shown that this analytic route is actually the inevitable outcome of applying the same mechanisms needed to acquire compositional expressions to randomly created holistic ones. The point here is that Wray is focusses on a cultural process of transition rather than a biological one.

This difference in emphasis does not to mean that accepting a holistic protolanguage commits us to a view that our protolanguage-speaking ancestors were genetically identical to us. Similarly a Bickertonian view of protolanguage is compatible with the notion that the first generations of anatomically modern humans had languages that were not identical in structure to our own. As I will discuss in the next section, the processes of cultural and biological evolution are both likely to be involved in the emergence of human language.

This brief overview has only really scratched the surface of the debate on what constitutes a viable theory of protolanguage (or indeed whether we need assume protolanguage at all). Readers interested in other authors' views on the debate between Wray and Bickerton are referred to: Hurford (2000) who proposes a distinction between analytic and synthetic routes to complex language; Arbib (2005) and Kirby (2001), for example, who discuss the plausibility of the analytic process;

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[5] Note that formulae in modern language are rather different since they appear to contain individual words. Of course, this is only possible once a fully modern human language with separate words already exists. Despite this difference, the argument is that the function and processing of these expressions in modern language and protolanguage is essentially the same.

Tallerman (2006) who sets out a series of problems for holistic protolanguage; and Smith (2006) who challenges the validity of Tallerman's arguments.

4. Evolutionary Mechanisms: the complex adaptive systems view

This chapter started with the view that the emergence of language constituted a major evolutionary transition because it introduced a new system for transmitting information, a feature shared by many other major transitions. When Maynard Smith & Szathmáry talk about the information that language is transmitting, they are referring to the unbounded semantic information that we can convey with linguistic expressions.

There is, however, another sense in which language is a novel system of information transmission. Because language is not completely innately coded, much of its structure must be learned. Most researchers (see, e.g., Pinker 1995 for review) agree that language learning can proceed normally with little, if any, reliable feedback in the way of reinforcement or negative evidence (i.e. the explicit labelling of children's incorrect output as errors by parents). In other words, language can be reliably acquired purely through the observation of instances of its use. In a very real sense, language not only transmits semantic information, but also *information about its own construction*.

This process of information transmission has been termed *iterated learning* to reflect the fact that linguistic behaviour is learned through observation of that behaviour in others who themselves learned that behaviour using the same mechanism (e.g., Kirby et al 2004). Language is therefore repeatedly transformed from external linguistic behaviour to internal linguistic representation to external linguistic behaviour and so on. What implications does this have for an evolutionary approach to language? A number of authors have argued that it means language is itself an evolutionary system, but one that operates on a cultural, rather than biological, timescale (e.g., Kirby 1999; Christiansen 1994; Deacon 1997; Croft 2000). As noted in the previous section, this does not rule out biological evolution as an explanatory mechanism, rather it is only part of the picture.

Biological evolution and cultural evolution (of which the transmission of information about the construction of language is a particular type) are both *dynamical systems* in that the transmission of information over time results in change of that information. In fact, they are not the only dynamical systems involved in language - individual learning is another one, operating at an even shorter timescale to that of culture and biological evolution.

What's particularly interesting about language as a natural system is that these three dynamical systems interact in non-trivial ways (see figure 4). The mechanisms for learning language are part of our biological inheritance, and are thus subject to biological evolution. It is these learning mechanisms that underpin the cultural process of linguistic transmission through iterated learning. Finally, the languages that emerge from the dynamics of the cultural evolution will in part determine the biological fitness of the individuals possessing them and ultimately impact on the evolutionary trajectory of the learning mechanisms for language. There is, therefore, a complex circle of interactions between these dynamical systems acting on three different time-scales.

Understanding the implications of this view of language is a significant theoretical challenge. A growing area of research into the evolution of language employs the methodology of *complex adaptive systems* research to tackle this challenge (see e.g., Kirby 2002 for a review). This approach uses computational or mathematical models of populations of individuals (usually referred to as *agents*) each embodying the basic learning mechanisms under study. Models of agents vary greatly form simple mathematical idealisations (Komarova & Nowak 2003) through abstract computational simulations (Brighton et al 2005) to physical instantiations in real robots (Steels 2003). However they are modelled, these agents interact, producing linguistic behaviour, and in so doing transmit their linguistic knowledge through iterated learning. In some models, there may be variation in the agents' learning mechanisms and this variation is inherited by agents' "offspring". Combined with some mechanism to measure the fitness of agents this implements biological evolution in addition to cultural transmission and individual learning.

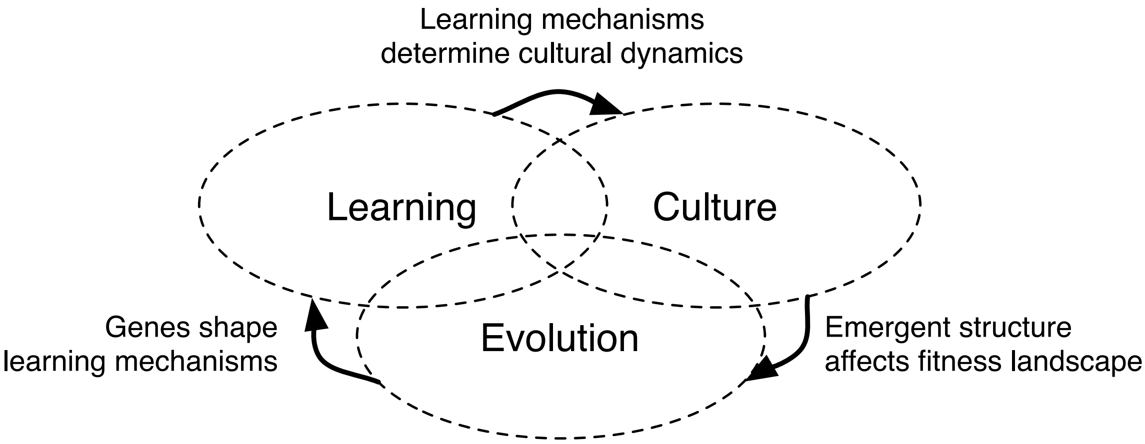

Figure 4*: Language emerges from the non-trivial interactions of three dynamical systems operating on three different timescales: individual learning, cultural transmission and biological evolution.*

This multiple dynamical systems approach to language evolution is still in its infancy, but it has already yielded interesting insights, particularly into the **structure** and **function** questions posed in the introduction:

- **Language and adaptation**. The adaptationist approach to explaining complex structure in human language appeals to an apparent fit of this structure to the function of communication (see, e.g. Pinker & Bloom 1990). This fit is assumed to be explained by adaptation of the innate language faculty by natural selection. This basic approach is familiar to many aspects of evolutionary psychology. The complex adaptive systems perspective, however, demonstrates that there are other potential explanations for adaptive complexity. Kirby (1999) shows how the process of cultural transmission itself can lead to adaptation of language to the needs of language users. The challenge therefore is to determine for each feature of language that we wish to explain whether natural selection or iterated learning is the right explanatory mechanism.
- **Bottlenecks and linguistic generalisation**. It is a widely recognised fact that the data available to the language-learning child is at best a noisy and limited reflection of the linguistic system that must be acquired (which is, after all, infinitely expressive). This "poverty of the stimulus" is often taken to be an argument for strong innate constraints on the language acquisition process (Chomsky 1965). Work on iterated learning (e.g., Zuidema 2003) points to a different consequence, however.

  We can think of the knowledge of language being forced every generation through a narrow bottleneck of linguistic experience. In models of iterated learning it has been found that it is this bottleneck that acts as the primary pressure to which the culturally evolving language must adapt. At the risk of oversimplifying, languages (or more correctly systems within languages) can only survive through iterated learning if they can be acquired from an impoverished sample of their output.

It turns out that in computational models the sorts of languages (or structures within languages) that emerge out of iterated learning when a bottleneck is in place are exactly those that we find in real language. More specifically, the presence of a transmission bottleneck eventually leads to the evolution of regularity in language, since a regular pattern can be learned even if not all the instances of that pattern are observed. As Hurford (2000) puts it, social transmission favours linguistic generalisation.

- **The Baldwin effect**. It is a common misconception that adaptation occurring within an individual organism's lifetime cannot affect genetic evolution unless we take a Lamarckian view of inheritance (i.e. that an individual's acquired characteristics are passed-on to its offspring). In a linguistic context, this quite reasonably implies that the fact that I have acquired English (as opposed to some other language) cannot influence the evolution of the language faculty.

  Perhaps surprisingly, very early in the history of evolutionary thinking (Baldwin 1896) it was pointed out that although acquired characters are not inherited this does not mean that they can't influence evolution. In fact, complex adaptive systems research has shown that if generations of agents are faced with some environmental problem that involves learning, if this problem is relatively constant, and if learning involves some cost, then natural selection can lead to learned knowledge becoming innate knowledge over time.

  Several researchers (e.g., Briscoe 2000; Turkel 2002) have suggested that the Baldwin effect has a natural application in the case of language evolution. Computational models provide support for the idea that this evolutionary mechanism could take us from a relatively domain-general learning mechanism to one which is specialised for language and which allows for just the kind of semi-constrained cross-linguistic variation that we find in real language.

  This is an area of ongoing research, and the Baldwin effect is not without its problems (see e.g., Yamauchi 2004). In fact, this may be only one of a number of evolutionary principles that come into play when multiple adaptive systems are brought together (see, for example, Deacon 2003; Ritchie & Kirby 2005). Previous work in the complex adaptive systems literature looked mainly at the interaction between learning and genetic evolution, but with language we must also take cultural evolution into account (Kirby & Hurford 1997; Smith 2002). It is likely to be some time before we have the solid theoretical grounding that will allow us to make straightforward predictions about the behaviour of the system shown in figure 4.

5. Conclusion

In the introduction, we saw that there are many questions that we might wish answered about the evolution of human language, each of which suggest a different approach to research and draw upon very different sorts of evidence. I briefly surveyed three different areas that are the subject of current controversy and active study.

This is, of course, just a small sample of what is a very active field. In particular, there was not space to look into the **function** question in much detail. For example, it is very much a matter for debate whether communication is the function of language that drove its evolution, and if so how the consequent problems of the evolution of altruistic behaviour are solved, and how such a cheap signalling system could nevertheless be trusted (Knight 1998). Other possible functions that have been discussed are internal "speech" (mentioned by Chomsky 2002), social grooming (Dunbar 1993), sexual display (Miller 2000), and alliance-forming (Dessalles 2000) among others.

We also have not looked in much detail at the types of evidence are available to constrain our theories of language evolution. Of course, the primary source of evidence should be language itself, and it is crucial that those researching language evolution pay attention to developments in linguistics, which aims to provide the best account of the phenomenon we are trying to understand. In addition, ongoing work in neuroscience, archaeology and genetics should further narrow down the set of plausible accounts of the evolution of language.

Finally, one of the biggest challenges that lies ahead will be trying to figure out if the different answers to the four evolutionary questions in section 1 are actually compatible with each other. For example, is a particular view of protolanguage that proposes multiple stages with intermediate forms compatible with a view of language with a minimal FLN? Do the adaptive mechanisms surveyed in section 3 constrain the kinds of protolanguage that are possible?

It is a perfectly acceptable research strategy to focus solely on one of the four questions, or a combination of them. However, ultimately we should be careful that our answers to any one of them do not preclude finding an answer to the others. This highlights an important and difficult challenge facing the study of language evolution: the need for cooperation between different disciplines and between researchers working on different aspects of the problem. Without this cooperation a satisfactory account of the evolution of human language, and therefore of human language itself, is likely to be elusive.

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