

Evolution of Language as one of the Major Evolutionary Transitions

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1 Introduction

The “original resources” available to humans has puzzled the founder of modern neuroscience, Santiago Ramon y Cajal. In his autobiography he writes:

“At that time, the generally accepted idea that the differences between the brain of [non-human] mammals (cat, dog, monkey, etc.) and that of man are only quantitative, seemed to me unlikely and even a little offensive to human dignity... but do not articulate language, the capability of abstraction, the ability to create concepts, and, finally, the art of inventing ingenious instruments... seem to indicate (even admitting fundamental structural correspondences with the animals) the existence of original resources, of something qualitatively new which justifies the psychological nobility of *Homo sapiens?*...”,

cited by De Felipe et al. ((16), p. 299).

Natural language is a unique communication and cultural inheritance system. In its practically unlimited hereditary potential it is similar to the genetic and the immune systems. The underlying principle is also similar in that all these systems are generative: they achieve unlimited capacity by the combination of limited primitives. The origin of natural language is the last of the major evolutionary transitions (39). Although later in society important transitions did happen in the way of storing, transmitting and using inherited information, they were not made possible or accompanied by relevant genetic changes in the biology of our species. In contrast, language has a genetic background, but it is an open question how a set of genes affects our language faculty. It is fair to say that with respect to their capacity to deal with the complexity of language, even so-called ‘linguistically trained’ animals are very far from us.

Understanding language origins and change is difficult because it involves three interwoven timescales and processes: individual learning, cultural transmission and biological evolution. These cannot be neatly separated from one another (9; 10; 11). The fact that a population uses some useful language that is culturally transmitted changes the fitness landscape of the population genetic processes.

Language has certain design features, such as symbolic reference, compositionality, recursion, and cultural transmission (30). Theories of language and language evolution can be divided into two sets of hypotheses: a nativist versus empiricist account and a non-adaptationist versus adaptationist account, respectively (K.

Smith, PhD Thesis, University of Edinburgh, 2003).

The *nativist paradigm* argues that language capacity is a collection of domain-specific cognitive skills that is unique to humans and that is somehow encoded into our genome. Perhaps the most famous proponent of this approach is Noam Chomsky, who coined the term 'language organ' and argued in favour of the uniqueness and the innateness of human linguistic skills (7). Different scholars agree with Chomsky on this issue (39; 33; 47; 48; 49). The *empiricist paradigm*, however, argues that linguistic performance by humans can be explained with domain-general learning techniques (54).

Fisher and Marcus ((19), p. 13) are right in stating that "In short, language is a rich computational system that simultaneously coordinates syntactic, semantic, phonological and pragmatic representations with each other, motor and sensory systems, and both the speaker's and listener's knowledge of the world. As such, tracing the genetic origins of language will require an understanding of a great number of sensory, motor and cognitive systems, of how they have changed individually, and of how the interactions between them have evolved." The study of language origins is however hampered by the fact that there is a critical lack of detailed understanding at all levels, including the linguistic one. There is no general agreement among linguists how language should be described: widely different approaches do exist and their proponents can have very tense scientific and other relationships. As a biologist I would maintain that symbolic reference combined with complicated syntax (including the capacity of recursion) is a least common denominator in this debate. Within this broad characterisation I just call attention to two approaches that have, perhaps surprisingly, a strongly chemical flavour. One is the minimalist programme of Chomsky (8) where the crucial operator is *merge*, the action of which triggers certain rearrangements of the representation of a sentence. There is a broad similarity between this proposal and chemical reactions (40). An even closer analogy between chemistry and linguistics can be detected in Steel's Fluid Construction Grammar (58; 59), in which semantic and syntactical 'valences' have to be filled for correct sentence construction and parsing. We should note that the roots of genetic inheritance are of course in chemistry, and that even at the phenomenological level Mendelian genetics was a stoichiometric paradigm, influenced by contemporary chemical understanding (elementary units that can be combined in certain *fixed proportions* give rise to new qualities). Chemical reactions can be also characterised by rewrite rules. It will take in-depth study to consider how deep this analogy goes. The deeper it goes, the more benefit one can hope from taking the analogy seriously.

In this chapter I shall briefly summarize views on adaptation and language, some relevant neurobiological and genetic facts, the presence or absence of recursion in animals, the possible role of genetic assimilation in language evolution, the prerequisites of language and the nature of human adaptive suite, possible evolutionary scenarios for the origin of natural language, the special difficulty of this last major transition, a possible modelling approach to the problem, and, finally, I give a summary showing that the transition from societies with protolanguage

to modern society with language indeed qualifies as a major transition. In this account I shall heavily rely of more detailed expositions (66; 65).

2 Contrasting views on language as adaptation

Non-adaptationist accounts of language evolution rely heavily on so-called ‘spandrels’ (25). The idea is that language or linguistic skills evolved not because it gave fitness advantage to its users; rather it evolved as a side effect of other skills as spandrels are side effect of architectural constraints. Chomsky again has a prominent role in this debate as the protagonist of the non-adaptationist approach. In the latest reworking of the theory (28), Chomsky and colleagues distinguish between the so-called ‘Faculty of Language in the Broad Sense’ (FLB) and ‘Faculty of Language in the Narrow Sense’ (FLN). They argue that FLB consists of skills that evolved in other animals as well as in humans, whereas FLN consists of only one skill (merge), which evolved in a different (unspecified) context and was then co-opted for linguistic use. However, that European starlings may be able to recognise context-free grammatical structures (i.e. hierarchical syntax (22) is somewhat contrary to Chomsky’s position given that it shows that precursor of the skill they have assigned to FLN (i.e. “merge”) may have independently evolved in other animals too; although a strict proof of appropriate parsing of these structures by starlings is lacking (see below).

The first *adaptationist* account of human language was by Darwin (14), later defended by Pinker and Bloom (48) in their influential paper about the Darwinian account of language. More specifically, these authors argued that language, as any complex adaptations, can only be explained by means of natural selection. This paper catalysed many linguists and biologists to study language and language evolution from the perspective of evolutionary biology and was followed by many influential publications (39; 33; 9; 10; 11; 35). Most recently, Pinker and Jackendoff (49) made a forceful defence of the adaptationist paradigm in response to Chomsky and colleagues (28).

I share the view that language is a complex, genetically influenced system for communication that has been under positive selection in the human lineage (49). The task of the modeller is then to try to model intermediate stages of a hypothetical scenario and, ultimately, to re-enact critical steps of the transition from protolanguage (3) to language. It cannot be denied that language is also a means for representation. This is probably most obvious for abstract concepts, for which the generative properties of language may lead to the emergence of a clear concept itself. This is well demonstrated for arithmetics: for instance, an Amazonian indigenous group lacks words for numbers greater than 5; hence they are unable to perform exact calculations in the range of larger numbers, but they have approximate arithmetics (46).

3 Notes on the neurobiology of language

On the neurobiological side I must call attention to the fact that some textbooks, e.g. (34) still give a distorted image of the neurobiological basis of language. It would be very simple to have the Wernicke and Broca areas of the left hemisphere for semantics and syntax, respectively. But the localisation of language components in the brain is extremely plastic, both between and within individuals (43; 42). Surprisingly, if a removal of the left hemisphere happens early enough, the patient can nearly completely retain his/her capacity to acquire language. This is of course in sharp contrast to the idea of anatomical modularity. It also puts severe limitation on the idea that it is only the afferent channels that changed in the evolution of the human brain: modality independence and the enormous brain plasticity in the localisation of language favour the idea that whatever has changed in the brain that has rendered it capable of linguistic processing must be a very widespread property of the neuronal networks (63). Components of language get localised somewhere in any particular brain in the most functionally ‘convenient’ parts available. Language is just a certain activity pattern of the brain that finds its habitat like an amoeba in a medium. The metaphor ‘language amoeba’ expresses the plasticity of language but it also calls attention to the fact that a large part of the human brain is apparently a potential habitat for it, but no such habitat seems to exist in non-human ape brains (63).

A dogma concerning the histological uniformity of homologous brain areas in different primate species has also been around for some time. Recent investigations do not support such a claim (16). In fact the primary visual cortex shows marked cytoarchitectonic variation (51), even between chimps and man. It is therefore not at all excluded that some of the species-specific differences in brain networks are genetically determined, and that some of these are crucial for our language capacity. But, as discussed above, these language-critical features must be a rather widespread network property. Genes affect language through the development of the brain. One could thus say that the origin of language is to a large extent an exercise in the linguistically relevant developmental genetics of the human brain (63).

The close genetic similarity between humans and chimps strongly suggests that the majority of changes relevant to the human condition are likely to have resulted from changes in gene regulation rather than from widespread changes of downstream structural genes. Recent genetic and genomic evidence corroborates this view. In contrast to other organs, genes expressed in the human brain seem almost always up-regulated relative to the homologous genes in chimp brains (6). The functional consequences of this consistent pattern await further analysis.

4 Towards a genetic approach to language

We know something about genetic changes more directly relevant to language. The FOXP2 gene was discovered to have mutated in an English-speaking family

(23; 24). It has a pleiotropic effect: it causes orofacial dyspraxia, but it also affects the morphology of language: affected patients must learn or form the past tense of verbs or the plurals of nouns case by case, and even after practice they do so differently from unaffected humans (see (37) for review). The gene has been under positive selection (17) in the past, which shows that there are genetically influenced important traits of language other than recursion (49), contrary to some opinions (28).

5 The status of recursion in animals and human

It does seem that the capacity to handle recursion is different from species to species. Although the relevant experiment must be conducted with chimps as well, it has been demonstrated that tamarin monkeys are insensitive to auditory patterns defined by more general phrase structure grammar, whereas they discover violations of input conforming to finite state grammar (20). Human adults are sensitive to both violations. Needless to say it would be very interesting to know the relevant sensitivities in apes and human children (preferably before they can talk fluently). It will be interesting to see what kind of experiment can produce consistent patterns in such a capacity in evolving neuronal networks, and then reverse engineer proficient networks to discover evolved mechanisms for this capacity. Thus a crucial element of syntax is center-embedded recursion that has been regarded as specific to humans. This view has recently been challenged by Gentner *et al.* (22) who believe to have demonstrated that European starlings recognize context-free grammar (CFG) with center-embedding. This experimental design was constructed under the influence of the former experiment by Fitch-Hauser experiment.

This paradigm percolated neurobiology as well, where electrophysiological and brain imaging studies were performed on patients working on linear and hierarchical sentence tasks (10, 11). The methodological problem with these studies is the same as in the case of the tamarin versus human and the starling experiments: since there is no need for real center-embedding (bracketing), the task can be solved by counting (7, 12). In real CFG sentences generated with the A^nB^n rule, words are bounded from the outside in, so that the first word is connected with the last one, the second word with the one before the last, etc. (Fig. 1.).

However, in the above-mentioned studies nothing implies these connections, thus there is no evidence that subjects recognize the center-embedded structure of the sentences. Indeed, these sentences can be correctly categorized by counting the number of As and Bs. If the numbers are equal and there is only one transition from As to Bs, then subjects seem to recognize it as CFG without understanding its hierarchical structure. For this, information beyond the strings themselves is required that makes embedding mandatory (12): a minimalist neural network satisfying these more stringent criteria has just been proposed.

There is a known human language, apparently with no recursion (18). It would be good to know how these particular people (speaking the Pirahã lan-

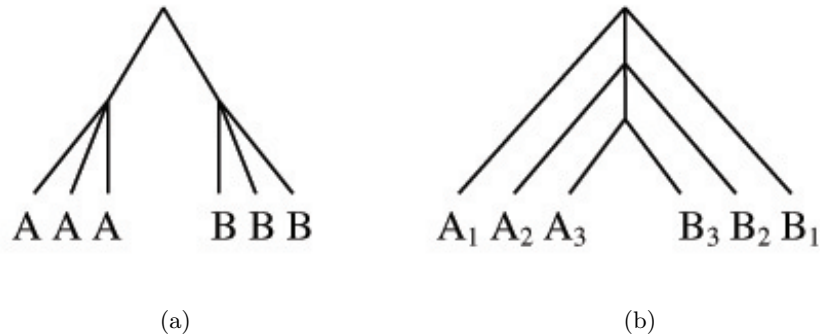


Fig. 1. Apparent (left) and real (right) CFG. The structure on the left can be parsed by simple counting; the tree on the right needs some knowledge of CFG because of the long-range dependencies (12; 13)

guage in the Amazon) manage recursion in other domains, such as object manipulation. Apes are very bad at recursion both in the theory of mind or ‘action grammar’ (26).

6 Genetic assimilation in language evolution

I mentioned before that the fact that language changes while the genetic background also changes (which must have been true especially for the initial phases of language evolution), the processes and timescales are interwoven. This opens up the possibility for genetic assimilation (the Baldwin effect). Some changes that each individual must learn at first can become hard-wired in the brain later. Some have endorsed (48), while others have doubted (15) the importance of this mechanism in language evolution. Deacon’s argument against it was that linguistic structures change so fast that there is no chance for the genetic system to assimilate any grammatical rule. This is likely to be true but not very important. There are linguistic operations, performed by neuronal computations, related to compositionality and recursion that must have appeared sometime in evolution. Whatever the explicit grammatical rules are, such operations must be executed.

Hence a much more likely scenario for the importance of genetic assimilation proposes that many operations must have first been learned, and those individuals whose brain was genetically preconditioned to a better (faster, more accurate) performance of these operations had a selective advantage (63). Learning was important in rendering the fitness landscape more climbable (29). This view is consonant with Rapoport’s (52) view of brain evolution. This thesis is also open for experimental test.

7 Prerequisites for language and the concept of a human-specific adaptive suite

Language needs certain prerequisites. There are some obvious prerequisites of language that are not especially relevant to our approach. For example, apes do not have a descended larynx or cortical control of their vocalisations. Undoubtedly, these traits must have evolved in the human lineage, but we do not think that they are indispensable for language as such. One could have a functional language with a smaller number of phonemes, and sign language (55) does not need either vocalisation or auditory analysis. Thus, we are mostly concerned with the *neuronal implementation* of linguistic operations, irrespective of the modality. It seems difficult to imagine the origin of language without capacities for teaching (which differs from learning), imitation, and some theory of mind (50). Apes are limited in all these capacities. It is fair to assume that these traits have undergone significant evolution because they were evolving together with language in the hominine lineage. To this one should add, not as a prerequisite, but as a significant human adaptation the ability to cooperate in large non-kin groups (39). These traits together form an *adaptive suit*, specific to humans. I suggest that in any selective scenario, capacities for teaching, imitation, some theory of mind, and complex cooperation must be rewarded, because an innate capacity for these renders language emergence more likely.

Various people (e.g. (50)) have called attention to that fact that besides language, efficient teaching (which differs from learning), imitation, and a developed theory of mind are also uniquely human resources. I also stress the trait of human cooperation (39), which is remarkable because we can cooperate even in large non-kin groups. My proposal is that these traits are not by accident together. They form an adaptive suite, and presumably they have coevolved in the last five million years in a synergistic fashion. The relevant image is a *co-evolutionary wheel* (Fig. 2): evolution along any of the radial spokes presumably gave a mileage to all the other capacities, even if the focus of selection may have changed spokes several times. This hypothesis is testable; and there is evidence in its favour already. Take the case of autism, for example. Affected people have a problem with the theory of mind, communication, and they can be seriously challenged in the strictly linguistic domain as well (19). The prediction is that there will be several-to-many genes found, that will have pleiotropic effects on more than one spoke of the wheel in Fig. 2.

8 Selective Scenarios for the Origin of Language

The issue of the origin of human language has provided fertile ground for speculation, and alternative theories have been proposed (62).

Most of the theories that suggest a given context for the evolution of human language attempt to account for its functional role. Given that, functionally, all of these theories are more or less plausible, it is almost impossible to decide on their usefulness based only on this criterion. However, recent game theoretical

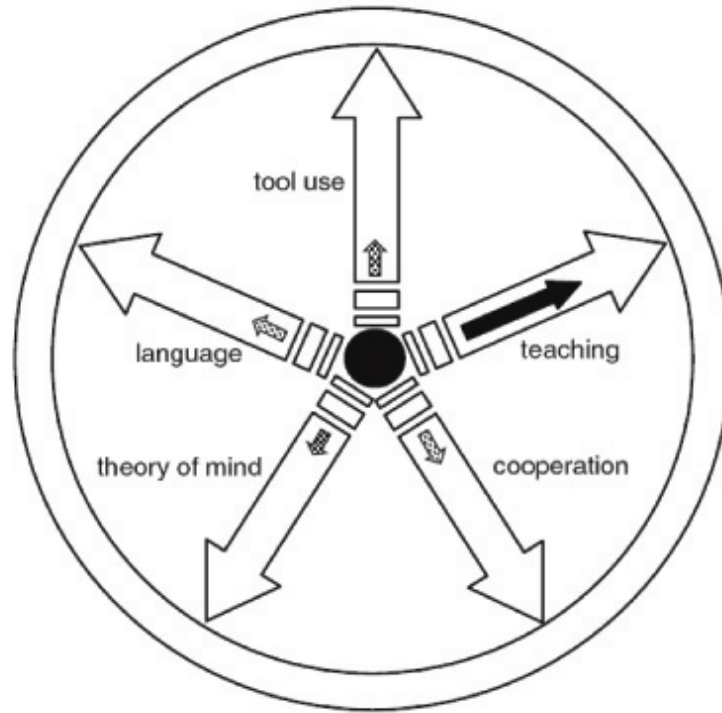


Fig. 2. The coevolutionary wheel and the human adaptive suite. In this example, direct selection on genetic variation is on teaching/docility (black arrow), but this gives some improvement, to varying degrees, in other dimensions (patterned arrows) as well.

research can help us evaluate various contexts. These criteria concern the interest of communicating parties and the cost of equilibrium signals.

The central issue is whether early linguistic communication was honest. If signal cost is the same for all signallers, then honest cost-free signalling can be evolutionarily stable only if there is no conflict of interest between the participants (38). If the cost of signals varies with the quality of the signaller, then the situation is more complicated. In this case, it is possible to construct cost functions that give an arbitrarily low cost at equilibrium even if there is a conflict of interest (31; 61; 36). In case of human language, the most obvious way to construct such a cost function is to punish dishonest signallers (36). However, this solution assumes that dishonest signallers can, on average, be detected (i.e. signals can be cross-checked); it also assumes that dishonest signallers are punished (which is a non-trivial assumption). Thus, one can conclude that conventional signals will be used when communicating about (i) coincident interest or (ii) verifiable aspects of conflicting interest; 'costly' signals will be used otherwise (36). Although

theory so far says nothing about the evolution of such systems of communication, there are a few computer simulations that suggest that honest cost-free communication evolves only if there is shared interest between the participants (5; 44; 27).

What does this tell us about the emergence of human language? The production cost of speech or gesturing appears to be low, thus human language consists of cost-free or low-cost signals at equilibrium (not counting time constraints). Thus, based on the above criteria, one should favour either those theories that propose a context with no conflict of interest (e.g. hunting, tool making, motherese, grooming or the group bonding and/or ritual theory) or a context in which there might be a conflict of interest but signals can be easily cross-checked. None of the theories fit the second context: for example, mating contract and gossiping both assume a context in which conflict of interest exists and signals cannot be easily cross-checked.

Explaining the evolution of human language is likely to remain a challenge for the coming decade. There is no single theory that could sufficiently answer all the questions about honesty and groundedness, power of generalisation, and uniqueness. Table 1 gives a summary of these criteria (62). As one can see most of the theories fail to answer the majority of the questions. Perhaps the easiest criterion to fulfil is shared interest, as there are a number of social situations which assume shared interest between communicating parties (such as hunting or contact calls). There are only two theories - 'tool making' (26) and 'hunting' (67)- that do significantly better than the others as they can answer three out of the four questions asked of them (Table 1). Thus, it might be tempting to say that some combination of the two could provide a series of selective scenarios that would fit all of our criteria. The most notable conclusion, however, is that all the theories fail to explain the uniqueness of human language. Thus, even though indirect evidence strongly suggests that the evolution of human language was selection limited, it remains difficult to envisage a scenario that would show why.

Although the different scenarios suggest all kinds of selective forces, none of these scenarios has been consistently implemented in a family of models. Given the limitations on experimentation on humans and chimps, researchers should consider implementing the different scenarios in various model-based settings. Ultimately, researchers should be able to re-enact the emergence of language in embodied and situated agents. The use of robots offers a unique and probably indispensable way of symbol grounding (basic words, via concepts, should be linked to physical reality (57)) and somatosensory feedback (actions, or results of actions, on behalf of the agent feed back into its own cognitive system via sensory channels (45)).

9 What made language origins difficult?

Some major transitions in evolution (such as the origin of multicellular organisms or that of social animals) occurred a number of times, whereas others (the origin of the genetic code, or language) seem to have been unique events (39). One

Table 1. The properties and the explanatory power of the various theories. We ask the following questions to evaluate the various alternative theories: (1) Honesty: Can the theory account for the honesty of early language, that is, is there a shared interest between the proposed communicating parties? (2) Groundedness: Can the concepts proposed by the theory grounded in reality? (3) Power of generalization: Can the theory account for the power of generalisation unique to human language? (4) Uniqueness: Can the theory account for the uniqueness of human language? As one can see most of the theories can answer only one or two questions, some none at all; only the tool making and hunting theories can answer three questions out of four. (“?”: no information available. Mod.: modality; T: thought, V: vocalisation, G: gestures). From Számadó & Szathmáry (62)

	Mod.	First words	Topic	#1	#2	#3	#4
1. Language as a mental tool (Burling, 1993)	T	?	?	Yes	No	Yes	No
2. Grooming hypothesis (Dunbar, 1998)	V	?	?	Yes	No	No	No
3. Gossip (Power, 1998)	V	“Faithful”, “Philander”	Social life	No	No	Yes	No
4. Tool making (Greenfield, 1998)	?	?	?	Yes	Yes	Yes	No
5. Mating contract (Deacon, 1997)	?	?	Social contract	No	No	No	No
6. Sexual selection (Miller, 2001)	?	?	Anything	No	No	No	No
7. Status for information (Desalles, 1998)	?	?	Valuable information	No	No	Yes	No
8. Song hypothesis (Vanechoutte & Skoyles, 1998)	V	?	?	No	No	No	No
9. Group bonding/ ritual (Knight, 1998)	?/V	?	?	Yes	No	No	No
10. Motherese (Falk, 2004)	V	“Mama”	Contact call	Yes	Yes	No	No
11. Hunting theories (Hewes, 1973; Washburn & Lancaster, 1968)	G/V	Prey animals	Coordination of the hunt	Yes	Yes	Yes	No

must be cautious with the word ‘unique’, however. Due to a lack of the ‘true’ phylogeny of all extinct and extant organisms, one can give it only an operational definition (64). If all the extant and fossil species, which possess traits due to a particular transition, share a last common ancestor after that transition, then the transition is said to be unique. Obviously, it is quite possible that there have been independent “trials”, as it were, but we do not have comparative or fossil evidence for them. What factors can lead to “true” uniqueness of a transition? A) The transition is variation-limited. This means that the set of requisite genetic alterations has a very low probability. “Constraints” operate here in a broad sense. B) The transition is selection-limited. This means that there is something special in the selective environment that can favour the fixation of otherwise not really rare variants. Abiotic and biotic factors can both contribute to this limitation. For example (41), a single mutation in the haemoglobin gene can confer on the coded protein a greater affinity for oxygen: yet such a mutation got fixed in some animals living at high altitudes only (such as the lama or the barred goose, the latter migrating over the Himalayas at an altitude of 9000 m).

There are interesting sub-cases for both types of limitation. For (A), one can always enquire about the time-scale. “Not enough time” means that given a short evolutionary time horizon, the requisite variations have a very low probability indeed, but this could change with a widened horizon. An interesting sub-case of (B) is “pre-emption”, meaning that the traits resulting from the transitions act via a selective overkill, and sweep through the biota so quickly that further evolutionary trials are competitively suppressed. The genetic code could be a case in point.

It is hard to assess at the moment why language is unique. Even the “not enough time” case could apply, which would be amusing. But pre-emption, due to the subsequent cultural evolution that language has triggered, may render further trials very difficult indeed. Let us point out, however, yet another consideration that indicates that language could be variation-limited in a deeper sense. The habitat of the language amoeba is a large, appropriately connected neural network: most of the information processing within the network elaborates on information coming from other parts of the network. There is a special type of processing likely to be required: that of hierarchically embedded syntactic structures. It is far from obvious how this can be achieved in a network full of cycles. One must be able to show how a stack memory (last in, first out) can be neurobiologically implemented.

10 A Possible Modelling Approach

Motivated by the surveyed observation, the modeller also would like to get a handle on the language problem. Clearly, purely linguistic modelling or the application of unnatural neural algorithms is not enlightening for a biologist. Experimentation is fine, except that there are severe (and understandable) practical and ethical constraints on physiological and genetic experiments of primates, including humans. Hence *in vivo* experiments and field observations should be

complemented by an *in silico* approach. Such an approach should ideally be based on the distillation of available biological knowledge, as presented above. The modelling framework must be flexible enough to accommodate the necessary genetic and neural details; with the complication that ‘necessary’ depends on the actual tasks and cannot always be set in advance. Such an approach cannot be based on an elegant but limited analytic model: rather, a flexible simulation platform is needed, which will be presented in this section (65).

A crucial difficulty of such a research programme is that we do not know how far one can go with contemporary understanding of the nervous system. With the biochemistry of the early twentieth century one had zero chance even to conceptualize aptly the problem of origin of life, let alone to solve it. By the same token crucial elements of the understanding of the brain may be a serious obstacle in our understanding of language origins from a biological point of view. This objection is serious. My response to it is that unless we try, we shall never know whether we have sufficient basic knowledge of neurobiology to tackle the language problem. A complete understanding of all the details of the brain is unlikely to be necessary. Also, crucial components of the language faculty (e.g. symbolic reference) may be understood in neurobiological terms without an understanding of other components (e.g. syntax).

11 Evolutionary Neurogenetic Algorithm (ENGA)

We have developed a software framework called Evolutionary Neurogenetic Algorithm (ENGA in short) which offers researchers a fine control over biological detail in their simulations. Our original intent was to create software with much potential for variability. That is, we wanted a piece of software which is general enough to allow for a wide range of experimentation but appears as a coherent system and does not fall apart into a loosest of unrelated pieces of code. This required careful specification and design; especially in partitioning it into modules and the specification of interfaces in a programme that has grown to about 90,000 lines of C++ code. In such a short communication it is impossible to acknowledge all researchers of all important input fields to this paper. We have been especially influenced by evolutionary robotics, such as the work by Baldassare et al. (2), and by the evolutionary approach to neuronal networks with indirect encoding by Rolls and Stringer (53). Our model is a recombinant of these approaches, with some key new elements, such as topographical network architecture.

The software is organized into packages that are built upon each other, i.e. there is a dependency hierarchy between them. This gives the architecture a layered nature so that lower modules do not know about the existence of higher modules. Layered design allows easy modifiability of higher levels without the need to modify lower levels. Moreover, each layer exposes an interface that can be used by any client, even those deviating from the original purpose of simulating evolution of embodied communicating agents. The genetic module, for example, can be used in any evolutionary computation, not only those evolving artificial

neural networks. We may as well talk about a multilevel software framework consisting of several modules that can be used individually or in combination with others to produce various kinds of evolutionary and neural computation related simulations.

The most important feature of the model is that it is deliberately *biomimetic*: within the constraints of computation, we intended to model real life, rather than artificial life. The most important element is *indirect genetic control* of the evolving agents: few genes specify a potentially very large neuronal network. This is very different from the merely engineering approach where each neuron and connection is affected by a dedicated gene. I refer for most details to (65); the ENGA platform is also briefly presented in the Appendix to this book (Chapter 20).

12 Summary: the origin of a language as a proper major evolutionary transition

There are some recurrent themes in the major transitions (39):

- (1) Independently replicating units come together to form a higher-level unit
- (2) Appearance of novel inheritance systems
- (3) Division of labour or combination of functions
- (4) Contingent irreversibility
- (5) Central control

I now briefly discuss the relevance of these themes to the origin of language in turn.

Ad 1. The transition to language did not happen with solitary, occasionally communicating individuals, but in social groups, where, because of cooperation, individual autarchy (a la Robinson) was practically impossible. In a recent analysis of the role of group selection in the origin of human altruism, Bowles ((4), p. 1569) writes: “empirical estimates show that genetic differences between early human groups are likely to have been great enough so that lethal intergroup competition could account for the evolution of altruism. Crucial to this process were distinctive human practices such as sharing food beyond the immediate family, monogamy, and other forms of reproductive levelling. These culturally transmitted practices presuppose advanced cognitive and linguistic capacities, possibly accounting for the distinctive forms of altruism found in our species”.

Ad 2. The last sentence of this quote points in the direction of the importance of language as an novel inheritance system. Just as powerful epigenetic inheritance was crucial for the origin of complex forms of multicellular organisms, language (as opposed to syntactically deficient protolanguage) was crucial for the origin of human society (32).

Ad 3. Division of labour was noticed in the context of human society by Adam Smith in the first place. Language allows the negotiated division of labour, which

allows the performance of complex tasks, which in turn allows the appearance of more complex societies (40)).

Ad 4. Sometimes after a major transition there is no way back. This is usually the case with the transitions that are unique in the sense that all individuals sharing the post-transition traits share also a common ancestor with those traits; the only known example is eukaryotic sex: parthenogenesis arose repeatedly in evolution. Although humans may individually fail to acquire language when raised under linguistic deprivation, we know of no human group who would have lost language. This is also presumably linked to the fact that humans need the group to live in: this is the “higher-level unit” element in the transition to the human society.

Ad 5. Central control has increased in human groups with time, but this is a matter that we leave to anthropology and political history.

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