Language from a biological perspective

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The faculty of language is unique to the human species. This implies that there are human-specific biological changes that lie at the basis of human language. However, it is not clear what the nature of such changes are, and how they could be shaped by evolution. In this paper, emphasis is laid on describing language in a Chomskyan manner, as a mental object. This serves as a standpoint to speculate about the biological basis of the emergence and evolution of language.

1. Introduction

Human language is seen as the last major transition in the evolution of life on earth (Szathmáry and Smith 1995). As far as we can tell, biological changes are wrought by the forces of evolution. This implies that human language must have been derived by neo-Darwinian principles, and that some of its aspects are coded in the human genome. Language represents a major break from other animal communication systems in that it permits the creation of limitless representations by the creative combination of a finite vocabulary, using recursion. In this regard, language can be compared to the genetic code, which uses a finite set of units (the DNA bases) to create an apparent infinity of proteins.

In this article, I focus specifically on the Chomskyan view of language. In this view, 'language' is considered in two senses of the word. In the everyday sense, language involves communication, dissemination of knowledge, social interactions, cultural transmission and a host of other functions[1]. In the more narrow sense, language is taken to refer to the internal, computational capacity that can be utilized for the various 'external' functions like commu-

nication. Chomsky (see Chomsky 2000, for a recent overview) explicitly formulated the study of language as a mental object. A mental object is understood to be an inner mechanism of the mind that produces the observed behaviours. The internal computational system of language is sometimes also referred to as "I-language", where the 'I' represents the Individual, Internal and Intentional nature of such a characterization. Intentional here refers to the fact that language is assumed to be a rule-based system; rather like a recipe to make sentences. In contrast to I-language, E-language is the characterization of a language as the External and Extensive set of observed behaviours, for example, a collection of actual utterances from a group of native speakers. In this article, it is suggested that in order to speculate about the biological basis of language, it is important to maintain the distinction between I-language and E-language.

I start by briefly outlining the study of language as structure. Then, since the rapid and consistent acquisition of language by infants places constraints on theories of the language faculty, I examine some issues in language acquisition that derive from a structural view of language. Next, the logic of the Minimalist account of the core of I-language is outlined.

With such a perspective of language, a biologically motivated, speculative view of the language faculty is offered. Rather than a precise biological theory of language,

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[1]For example to "...satisfy [man]'s deep need to complain." (Lily Tomlin).

this article is intended as a hypothetical sketch that tries to draw analogies between biology and language. Hopefully, such a perspective might provide alternate ways to thinking about biological aspects of language and the mind.

2. Structural equivalence

Although the language faculty must have a genetic component shared by all the humans, the 6,000 or so extant languages of the world appear to be very different on the surface. Simplifying somewhat, learning a language requires, amongst other things, learning the lexicon (the words), the phonology (sound patterns) as well as the rules of syntax, all of which can vary substantially across languages. Acquiring the lexicon as well as the phonology is a complex problem and some aspects must be explicitly learnt. Thus, whether the common pet animal is referred to as 'dog' or 'kutra', or whether unaspirated and aspirated stops count as distinct phonemes, would depend on whether the learner was exposed to English or to Marathi (e.g. Hall and Waxman 2004).

Learning the syntax refers to learning the rules for productively combining the words of the language into larger phrases. 'Productively', since not every combination of words is well-formed (grammatical), and the language learner must learn how to create combinations that are well-formed. Generative linguists have tried to characterize the rule-like nature of natural languages. For example, it is possible to treat the English sentence

$$\text{John}^S \text{ kisses}^V \text{ Mary}^O. \tag{1}$$

as the symbolic structure, "[Subject [[transitive Verb] [direct Object]]]", or as the tree:
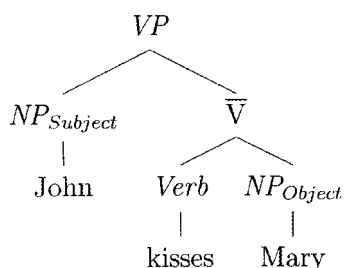
$\overline{\text{V}}$ (vee-bar) is an abstract, intermediate level, and the entire structure (VP) is technically a Verb Phrase. This sentence can then be directly compared with its semantically identical counterpart in Italian, as in (2), or to a different, but structurally similar sentence in English as in (3).

$$\text{Gianni}^S \text{ bacia}^V \text{ Maria}^O. \tag{2}$$

$$\text{Uma}^S \text{ kills}^V \text{ Bill}^O. \tag{3}$$

Such investigations reveal that, structurally speaking, languages appear to have much more in common than can be seen from the surface. However, languages differ even in their syntactic structures. For example, in Hindi, the sentence in (1) would be:

$$\text{John-ne}^S \text{ Mary-ko}^O \text{ chuma}^V. \tag{4}$$

That is, the order of the O(bject) and the V(erb) are different in English and in Hindi. There are several such systematic structural differences between languages. For example, while Italian and English have the same order of S-V-O, Italian does not have the requirement that the subject of a phrase be explicitly pronounced as does English. Thus, the English phrase *He writes* can be translated into Italian either as *Lui scrive*, or merely as *Scrive* ("Writes"). How can such variation be accounted for in the view that the language faculty is universal at the syntactic level?

Chomsky (e.g. Chomsky 1981a,b) proposed that the language universals can be divided into two kinds. The Principles are those that are fixed for all languages, and the Parameters are those that can take one of two, language-specific values. In this Principles and Parameters (P & P) approach, English and Italian differ in that English has the *Null-Subject parameter* set to 'no', while Italian has it set to 'yes' (thus Italian allows constructions that lack an overt subject). English and Italian together differ from Hindi in that Hindi has the *Head-Complement parameter set* to Complement-Head, while English and Italian have the same, Head-Complement setting. The Head-Complement parameter describes a structural relation between two entities, one of which is a word (a lexical item, called the Head), and the other is, most generally, a phrase (the Complement). For example, in the VP in (1), the Head is the verb 'kisses', which takes the Complement 'Mary'. The structural position occupied by the Subject of the VP ('John') in (1) is referred to as the *Specifier*.

The Head of a phrase can also be a noun, a preposition, or an adjective. In a significant generalization, Chomsky and colleagues proposed that all phrases have the same general structure, represented as:
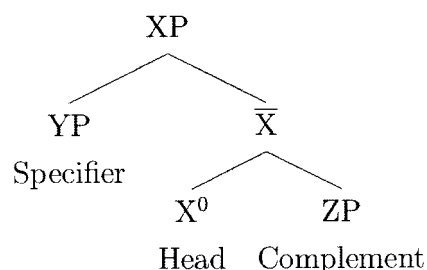
If the Head (X^0) is a verb, then the phrase is a VP as in (1). If X^0 is a preposition, then the phrase is a PP and so

on[2]. Notice that the structure in the tree above describes a Head-Complement language like English. For Hindi the order of the Head and the Complement would be interchanged.

Thus the Head-Complement parameter describes the structural relation inside different kinds of phrases, like Noun Phrases, Verb Phrases and Prepositional Phrases. Mark Baker (2002) suggests a view of the system of grammar as analogous to the atomic theory of matter. That is, just as matter is made up of the combination of a relatively small number of atoms, so are different languages a result of different choices of a few basic parameters.

Given that language is recursive, the Head-Complement parameter would come into play at each level of recursion. For example, the VP in (1) can be embedded inside another VP to give:

$$\text{Uma}^S \text{ said}^V \text{ [that John}^S \text{ kisses}^V \text{ Mary}^O]^O \qquad (5)$$

Here, the original VP is now part of the object of the verb 'said'; it is part of the Complement of the Head (the main verb).

The structural view of language suggests that if a language displays, for example, the order verb-object (corresponding to the Head-Complement setting of the Head-Complement parameter), it should also display a host of other properties, which are unrelated on the surface. Thus, such languages should have adpositions before noun phrases, complementizers before subordinate clauses, verbs before participle phrases and so on. Indeed, in a survey of 625 languages that cover language genera from large geographical areas, Dryer (1992) observed (statistically) significant correlations for such properties (amongst others). Such a result is particularly striking when one considers that many of these languages have diverged a long time ago. Take the case of Polish (Slavic family) and English (Germanic family). It is estimated that these families diverged around 6,500 years ago (Gray and Atkinson 2003). Given that they share a host of seemingly unrelated syntactic properties, it is hypothesized that these shared properties have an origin in similar constraints in the human language system.

3. Language acquisition

If languages indeed do have deep similarities, and if these can be adequately captured by a theory like P & P, then such a theory would be useful in explaining language acquisition as well. This is because learning the grammatical rules of a language would be reduced to learning the correct setting of the parameters for that particular language. As we saw, the cross-language correlations captured by the Head-Complement parameter can account for the structure of a large number of different sentences. Thus, for example, if an infant observed a verb preceding its direct object, it might deduce that the language is a Head-Complement language. Based on this single observation, it would be biased to assume that, in its target language, adpositions came before their related noun phrases, complementizers came before subordinate clauses and so on.

The view of language as an innately specified mental object also explains language acquisition when the input is impoverished. Such is the case in the process of creolization (e.g. Bickerton 1984, 1999). In these situations, language learners are exposed to an impoverished 'language' (a Pidgin). However, in the space of just one generation, there emerges a Creole, which more closely resembles any other natural language. Similarly, deaf children born in hearing families are often exposed to a primitive sign language that their family uses for communication. Even in these cases, the children do not merely mimic their input, but 'naturalize' it to resemble natural languages (e.g. Goldin-Meadow and Mylander 1990).

Such data have led researchers to hypothesize that the linguistic input might contain triggers that influence the development of the language computational system (e.g. Anderson and Lightfoot 2002). The term 'trigger' has the same connotation as in ethology, where it refers to an environmental stimulus that releases observed patterns of behaviour. However, it has been much harder to characterize the nature of linguistic triggers.

In order to look for possible triggers in the speech signal, we examined matched speech samples from several different languages. Infant research had previously uncovered a precocious ability of neonates to discriminate certain pairs of non-maternal languages, but not others (e.g. Nazzi *et al* 1998). Ramus *et al* (2000) demonstrated that a particular characteristic of languages, the percentage of time per utterance spent producing vowels (%V), could explain the pattern of language discrimination by infants. Indeed, it has been known that infants are differentially sensitive to vowels and consonants (e.g. Bertoncini *et al* 1988). Based on a variety of such observations (Shukla M, Nespor M and Mehler J, unpublished results), we looked for correlational evidence that the cue %V was related to morphosyntactic properties of language.

In a corpus of fourteen languages, we found that the value of %V was indeed related to several morphosyntactic properties of the languages. To summarize, these properties included fixedness of word order, degree of agglutination, simplicity of the syllabic repertoires as well as the value of the Head-Complement parameter (Shukla M, Nespor M and Mehler J, unpublished results). For exam-

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[2]This is referred to as the *X-bar theory*, after the intermediate level of representation, $\overline{X}$ (Chomsky 1970; Jackendoff 1977).

ple, the lowest value of %V for the Complement-Head languages was higher than the highest value of %V for the Head-Complement languages. We can thus tentatively conclude that certain properties of language might be triggered upon mere exposure to speech.

This observation is in the general spirit of 'Phonological Bootstrapping' (e.g. Gleitman and Wanner 1982; Morgan and Demuth 1996; Nespor *et al* 1996). Briefly stated, it is the hypothesis that properties of the sound patterns of languages might bootstrap syntactic properties. Why should the properties of the sound system of a language be related to the pattern of syntax? In order to discuss a (very hypothetical) possibility, it is first necessary to sketch out a formulation of the syntax of language termed 'Minimalism'. The Minimalist account of language also paves the way to sketching a possible scenario for the evolution of language.

4. Minimal minimalism

As discussed before, language in the Chomskyan framework is proposed to have a core syntactic computation, which is the (mental) object of inquiry. In the Minimalist Program, Chomsky proposed that the core of language is the single operation, Merge, along with how Merge interacts with at least two other systems: the Conceptual-Intentional and the Sensory-Motor (Chomsky 1995; Hauser *et al* 2002).

All natural languages demonstrate the property of being able to create recursive structures. In addition, language is extensively used to express meaningful propositions and to communicate these to other speakers of the language. In minimalism, the bare bones of language are seen as a recursive core, constrained by at least two interfaces. The first is a conceptual-intentional system. This system is involved in computing meaning. The second is a sensory-motor system. This system is used to externalize language through gestures (vocal or otherwise), and can thus be used in communication. Hauser *et al* (2002) suggest that the evolution of the recursive system of Merge and the two interfaces (which they identify with the Faculty of Language – Narrow sense, or FLN) might be the only necessary condition for the evolution of language. In the rest of the article, the focus shall be mainly on the core computation, Merge.

This proposal is based on the idea that, at a minimum, language involves the ability to recursively combine lexical items. In Merge, any two elements, say x and y, can be combined to create, most simply, the set $\{x, y\}$[3]. The system is hierarchical and recursive since the sets that are

created as a result of combining two elements are themselves able to participate as elementary objects in subsequent Merge operations. Thus, in a subsequent step, the element z can be Merged with the element $\{x, y\}$ to create the element $\{z, \{x, y\}\}$. Merge can also create movement. For example, in the English sentence, *Mary, John likes* (infrequent in English, but more common in languages with a greater freedom in word order, like Hindi), it is postulated that the underlying representation is of the form *Mary, John likes* [*Mary*]. In older terminology, the original 'Mary', the object of the verb 'likes', was said to have *moved* to a higher position, leaving behind an unpronounced *trace*. Merge accommodates such so-called movement by assuming that the underlying representation (applying successive Merge operations) is of the form:

$$\{y, \{z, \{x, y\}\}\}$$

Mary, y $\qquad$ $\{z, \{x, y\}\}$

John, z $\qquad$ $\{x, y\}$

likes, x $\quad$ Mary, y
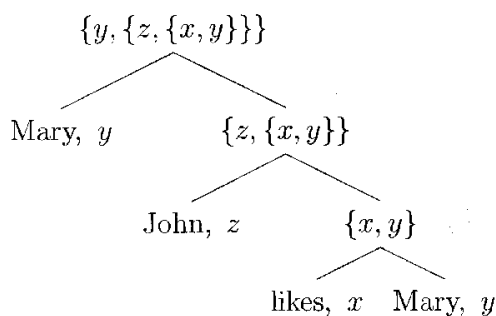
While Merge can produce such structures, the way they are actually realized (as speech, for example), would depend on their interaction with the rest of the cognitive architecture. For instance, an interaction with the sensory-motor systems might result in the second instance of 'Mary' not being pronounced (perhaps for reasons of economy).

5. A hypothetical evolutionary scenario

It is not easy to reconstruct the evolution of a mental trait like language. Unlike physical traits, language does not itself leave tangible traces of its evolutionary and developmental history. However, several researchers have proposed that the observed features of language might represent adapted or exapted traits (e.g. Bickerton 1990; Pinker and Bloom 1990).

With Merge in mind, one might now sketch a possible evolutionary scenario. Initially, proto-humans had a limited conceptual-intentional system. If the mechanism that accessed such a system acquired Merge, then it would gain the possibility to create hierarchic, recursively built, structured semantic representations[4]. Since Merge is re-

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[3]In general, it is also necessary to specify what is the nature of the object (the set) created by Merge, but this is set aside in the present discussion.

[4]The question of where Merge might have arisen from is taken up in the section 'Acquiring biological function'.

cursive, the system could use just a few concepts to build up rich semantic representations. The resulting humans would thus have a rich internal system of semantic representation.

Notice that such a view of the innovation of Merge has a direct fitness benefit at the individual level. It is clear that for efficient communication, both the speaker and the listener must have appropriate language skills; there needs to be both a coder and a decoder. That is, if language evolved primarily for communication, it would require concomitant evolutionary changes for there to be both a speech (or sign language) producer as well as receiver. In the scenario sketched above, the primary innovation of something like Merge provides a means for expanding the semantic space of an individual, providing individual-level selection. At a subsequent stage, there would have been the recruitment of production facilities in order to use the pre-existing system also for communication.

In this view, the core of language is a single operation, constrained by the semantic system. The output of this system is subject to further constraints of the communication system, be it speech or sign, to produce what might be called language-as-communication. Most of the observed grammatical properties of language are to be understood as being derived from the interaction between the core of language (Merge) and the two 'interfaces', one semantic and one for output.

One consequence of such a view is that the observed variation in language might be a reflection of different possible solutions to the problem of interfacing Merge and the conceptual-intentional system with the sensory-motor system. If such a view is true, this might constitute a potential explanation for phonological bootstrapping in language acquisition, mentioned above. That is, if language variation results from different solutions to the interface problem, then fixing a particular language might impact the very organization of the sensory-motor interface. Prosodic bootstrapping can then be construed as decoding which of the possible sensory-motor interfaces a given language implements, based on the organization of the sound structure of that language.

Thus, in this view, properties of language that are important, for example in communication, might have developed at a stage after the emergence of Merge. Such a view has been recently criticized by Pinker and Jackendoff (2005). These authors view the claim that language-as-recursion preceded language-for-communication as incompatible, given the (impressive) literature they survey. However, it is not clear why the cognitive apparatus for language-as-communication, for example, (which might even be specific to language-as-communication) coming after the emergence of Merge is *incompatible* with the scenario sketched above. To be clear, this is not to say

that language-as-communication might not involve specific computations. Indeed, language-for-communication might require several evolutionary adaptations like fine motor control for speech. The distinction is being made between those aspects of language that are necessary for all languages (like recursion) and those that appear to be specific to certain languages (like the property of having null-subjects).

Thus far, an attempt was made to describe the language system as consisting of an innate, core computational system. The rest of the language 'superstructure' is seen as being built upon the core computational system, perhaps even involving novel adaptations, like the lowered larynx that makes complex speech possible (e.g. Lieberman *et al* 1969; Fitch 2000). The following sections briefly consider the notion of innateness and the acquisition of novel function in some biological systems. Analogies are drawn between such systems and the human language system in order to gain a biological perspective into language.

6. Innateness in the mammalian brain

In order to look at innateness in the mammalian brain, consider the case of sensory 'maps' in the cortex. Electrophysiological as well as cytoarchitectonic studies of mammalian cortices have revealed that the sensory systems are reflected in the cortex as topographical 'maps', which are modular at a local level (Kaas 1997). For example, the primate visual cortex contains a map of the retina, such that adjacent areas in the retina correspond to adjacent areas on the cortical surface (Hubel and Wiesel 1968). In addition, within such a retinotopic map, there are subdivisions that compute different aspects of the same portion of the retinal image, for example the orientation (Livingstone and Hubel 1988). Similarly, somatosensory areas reflect the layout of the body plan of the animal (Merzenich *et al* 1978).

Comparative studies have revealed that within the topographic maps, the amount of cortical area devoted to the different organs depends on the ecological significance of the organ. For example, the 22-rayed nose of the star-nosed mole, which is an important organ for exploration has a disproportionately large representation within the somatosensory cortex of the animal (Catania and Kaas 1995). In addition, comparative studies have also revealed that the nature of the cortical maps of different species reflects their ecological niche specialization. For example, Krubitzer and Kahn (2003) compared the cortical areas of three mammalian species with approximately similar-sized cortical sheets. They found that the most relevant cortical area, given the ecology of the animal, had the largest representation. So, while the nocturnal

mouse has a large somatosensory area, the echolocating ghost bat has a large auditory area, and the diurnal sort-tailed opossum has a large visual cortex.

Are such cortical areas set up due to innate (genetic) factors, or do they arise due to a change in the input to the cortex? There is evidence to suggest that the mature form of the cortex has some innate properties, but these are tuned by the developmental history of the animal (see Krubitzer and Huffman 2000, for a review). For example, Bishop *et al* (2000) studied the role of two regulatory genes, *Emx2* and *Pax6* in the developing mouse neocortex. These genes are expressed in two opposing gradients along the rostrocaudal axis of the developing neocortical ventricular zone (reminiscent of *bicoid* and *nanos* in the *Drosophila* system). These authors showed that altering the pattern of expression of *Emx2* and *Pax6* changed the pattern of molecular markers and area-specific connections in a manner consistent with their countergradients of expression. On the other side, there is plenty of evidence that supports the notion that the cortical map is plastic; changes in the periphery causes reorganization of the cortical map (see Recanzone 2000, for a review).

Such an interaction between innately specified and environmentally driven development of the cortex is observed even for computational modules inside primary sensory areas. One example is the development and maintenance of orientation columns in the mammalian visual cortex. Sur and colleagues (e.g. Angelucci *et al* 1998; Melchner *et al* 2000; Sharma *et al* 2000) rewired the ferret cortex such that visual input from the thalamus was redirected to the auditory cortex. Such studies indicate that while some components of the cortical maps might be derived from intrinsic, cortical cues, others might be the result of an interaction with peripheral organs, mediated by patterned electrical activity (Sur and Leamey 2001).

The conclusion that can be drawn from this brief view of areal specialization in the cortex indicates that cortical circuits may be best thought of as being (i) moulded by genetic determinants in the form of molecular and intrinsic, electrical and cellular signals, as well as (ii) an interaction with the environment, mainly as changes in the patterned activity received at the cortex. If the cortical circuitry can be thought of as representing the cortical computations, we can conclude that cortical computations have both innate and environmentally driven components (see also Marcus 2004).

It is in this sense that we can consider language. The biological hypothesis of a linguistic theory like Principles and Parameters would be that the core computations that underly language (i) have an innate component, determined by genetic and cellular factors intrinsic to the developing brain, corresponding to the 'Principles', and (ii) their precise nature is shaped by activity patterns, determined by the nature of the incoming, language-relevant signals, which would correspond to the 'Parameters'. Such

signals might be, for example, properties of the speech signal like %V.

The research surveyed in this section provides a biologically based view of thinking about the process of the acquisition of the computations underlying language, and what 'innateness' might be taken to mean. In the next section, we shall examine a possible way in which the computational core of language (Merge) might have been acquired.

7. Acquiring biological function

How can novel biological function be acquired? Hauser *et al* (2002) propose that since FLN might be the computational core of syntax, and since this embodies recursion (Merge), it might have been derived from another cognitive domain that also requires recursion, but is not specific to humans, like navigational systems or social interactions. Indeed, hierarchical, recursive structures can also be seen in the planning of motor movements, for example in throwing a ball (e.g. Calvin and Bickerton 2000, chapter 12). In this section, the precise question of where FLN came from is set aside. Instead, we can ask a related question: what do we know about the acquisition of novel function in biological evolution that can help us think about the acquisition of something like Merge?

One possible way in which novel function can be acquired can be attributed to Susumu Ohno (e.g. Ohno 1970), and can be described as 'duplicate-and-evolve'. One well studied example that illustrates this idea is the evolution of the animal body plan brought about by the Hox genes (McGinnis and Krumlauf 1992). These genes encode transcription factors and are responsible for patterning the animal body along the anterior-posterior axis. Comparative analysis reveals an evolutionary history characterized by tandem and whole-cluster duplication events. Thus, while *Drosophila* has a single-cluster organization of the Hox genes, tetrapod vertebrates have four clusters of Hox genes, presumably as a result of genome duplication (e.g. Sidow 1996). It is thought that upon duplication, the paralogs of the original gene would be free to evolve rapidly, thus possibly bringing evolutionary innovation (e.g. Pavlopoulos and Averof 2002). Thus, morphological changes in the vertebrate line might have been caused by the rapid evolution of duplicated paralogs. The story is naturally far more complicated. Evolutionary change can be brought about not just by change in the Hox genes, but also in their regulatory sequences, in the addition of elements to such genes as well as changes in downstream targets (see, e.g. Gibson 1999).

Recent studies support the hypothesis that the duplicate-and-evolve scenario might be correct. For instance, Kondrashov *et al* (2002) evaluated selection strengths on

recently duplicated and unduplicated (but similarly diverged) genes in 23 bacterial, six archaeal and seven eukayotic genomes. These authors found that recently duplicated genes (paralogs) evolve faster than similar, unduplicated othologs, although they do not appear to undergo a phase of neutral evolution. Gu *et al* (2003) estimate that in the genome of the yeast *Saccharomyces cerevisiae*, a quarter of all genes exist as duplicates. These authors found a significantly higher probability of functional compensation of a duplicated gene, suggesting that robustness of genetic networks might be the functional reason why paralogs do not undergo a phase of neutral evolution. Recently, Gu *et al* (2004) found that duplicate genes tend to cause expression divergences between *Drosophila* species (or strains) to evolve faster than do single-copy genes.

It is still a long way from the evolution of genetic networks and body plans to the evolution of new cognitive capacities. The thesis being suggested here is that, in the same way that duplication-and-evolution might result in evolutionary innovation, for example of the body plan, duplication-and-evolution of cognitive modules might lead to cognitive innovation. Such cognitive modules may be thought of as cortical circuits that arise, as suggested in the previous section, due to inherent (genetic) properties of the developing brain and the influence of the environment. As yet we do not have a clear picture of what cortical circuits for cognitive modules might look like; these are suggestions by analogy as to how they might have evolved.

Indeed, studies in artificial intelligence (AI) provide some clues that such a view might be correct. Calabretta *et al* (1998a,b) utilized the Artificial Life modelling approach in robots with 'neuronal' architectures to show that duplication of functional 'units' leads to their functional specialization. They find that there is less functional specialization upon the duplication of units when function is distributed amongst the units than in a modular architecture (Calabretta *et al* 2000; Calabretta and Parisi 2004).

The assumption that the core computation of language is recursion (Merge) suggests that if there already existed a module for recursion in another system, then small genetic changes might have caused the duplication of such a module in the semantic system, such that semantic concepts could be hierarchically and recursively built up. This might represent a stage in evolution prior to language-as-communication. Perhaps in such a stage the human species had only something like *Mentalese* (e.g. Fodor 1975; Fodor and Pylyshyn 1988), a personal language-of-thought. This would set the stage for the evolution of language-as-communication.

Currently, not much is known about the genetic events that might have led to the evolution of language, or of its computational core. However, recent genetic research has uncovered at least one locus on the human chromosome 7, SPCH1, which is associated with an inheritable language deficit (Fisher *et al* 1998). This region was found to contain a gene, *FOXP2*, a mutation in which conferred severe speech and language difficulties (Lai *et al* 2001; Enard *et al* 2002). This gene affects speech and language, but also other cognitive capacities. While such studies have not yet revealed how the language faculty evolved, they hold the promise for dissecting pathways underlying speech and language (Fisher *et al* 2003; Marcus and Fisher 2003; see also Marcus 2004).

8. Conclusions

In this brief survey, a separation was made between language-as-computation and ways in which such a computation might be used, for example in communication. Such a view necessarily ignores the intricacies of language-as-communication, which might have evolved various specific adaptations in attaining its current status (e.g. Pinker and Jackendoff 2004). The separation of language-as-computation from language-as-communication is central in understanding the speculative, biologically based view suggested in this article.

It might turn out to be the case that several of the properties of language that are of interest to linguists (movement, subjacency) are related to the interface between the core computations and how these are used in language-as-communication. An interesting prediction of this viewpoint is that proposed universal principles of language might be modality specific. This is because interfacing language-as-computation onto the output system for speech might have different constraints than interfacing language-as-computation onto, for example, the output system of a sign language[5].

This of course does not prevent the exploration of language-as-communication as a mental object in itself. Indeed, there is a substantial body of generative linguistics that provides a detailed analysis of observed grammatical properties of scores of languages. Further, cross-disciplinary studies (see Hauser *et al* 2002) are needed to clarify the workings of the communicative and the core computational aspects of language.

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