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The evolution of the Faculty of Language from a Chomskyan perspective: bridging linguistics and biology

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Summary - *While language was traditionally considered a purely cultural trait, the advent of Noam Chomsky's Generative Grammar in the second half of the twentieth century dramatically challenged that view. According to that theory, language is an innate feature, part of the human biological endowment. If language is indeed innate, it had to biologically evolve. This review has two main objectives: firstly, it characterizes from a Chomskyan perspective the evolutionary processes by which language could have come into being. Secondly, it proposes a new method for interpreting the archaeological record that radically differs from the usual types of evidence Paleoanthropology has concentrated on when dealing with language evolution: while archaeological remains have usually been regarded from the view of the behavior they could be associated with, the paper will consider archaeological remains from the view of the computational processes and capabilities at work for their production. This computational approach, illustrated with a computational analysis of prehistoric geometric engravings, will be used to challenge the usual generative thinking on language evolution, based on the high specificity of language. The paper argues that the biological machinery of language is neither specifically linguistic nor specifically human, although language itself can still be considered a species-specific innate trait. From such a view, language would be one of the consequences of a slight modification operated on an ancestral architecture shared with vertebrates.*

Keywords - *Language evolution, Faculty of language, Nativism, Generative Grammar, Computational complexity, Prehistoric geometric engravings.*

Introduction

Language is very remarkable from the evolutionary perspective. In fact, its emergence has been considered one of the eight 'main transitions' in the evolution of life (Maynard-Smith & Szathmáry, 1999). In addition, language is perceived as the hallmark of humankind, the "human capacity that so clearly distinguishes our species *Homo sapiens* today" (Tattersall, 2010, p. 193). Therefore, its origins and evolution is an important issue, not just from a linguistic point of view, but from the wider perspective of human evolution.

That said, a question comes to the fore: is language a cultural or a biological trait? In the first half of the twentieth century, language was taken to be a purely cultural trait, deriving from our great intelligence and unlimited learning capacities. However, in the second half of the century, the advent of Noam Chomsky's Generative Grammar made it possible to offer a radically different answer: language is a species-specific trait, a part of our biological endowment. If language is indeed innate, it had to biologically evolve in the species. This raises exciting questions: Is language a uniquely human trait, or is it based on mechanisms shared with other species? Did language evolve from animal communication? Was language the exclusive province of *Homo sapiens*, or was it possessed by other hominid species as well? Did language evolve by natural selection (i.e. adaptively and gradually)? When can language be traced back to in Prehistory?

The first aim of this paper is to provide answers to questions like those from a generative perspective. Needless to say, because language evolution is a very difficult issue (the hardest problem in science, according to Christiansen & Kirby, 2003), some aspects involved in it are still in the dark and cannot receive a final answer. On the other hand, every theory is the result of a collective effort. Accordingly, the paper aims at erecting a synthesis between Chomsky's own thoughts on the matter and contributions from many other generative scholars. In some cases, the paper will even depart from the positions sustained by mainstream Generative Grammar, although without the abandonment of its core theoretical premises.

The second main objective of the paper may become especially interesting for Paleoanthropology: a new method for reading and interpreting the archaeological record is offered which strongly departs from the usual types of evidence Paleoanthropology has adduced when concerned with the timing that licenses the best inference to the evolution of language (and cognition). Archaeological remains have usually been regarded from the perspective of the behavior they could be associated with (symbolic, technological, social, etc.). However, it is also possible to consider them from the perspective of the mental computational processes and capabilities required for their production. This computational approach seeks to analyze purely formal features in archaeological objects that may reveal a language-like computational complexity. Such an approach, first proposed by Piattelli-Palmarini & Uriagereka (2005) and Camps & Uriagereka (2006) for analyzing evidence for knotting in the archaeological record, will be further extended, through an innovative computational analysis of prehistoric geometric engravings.

The exposition and illustration of the computational approach is the trigger for challenging the usual generative thinking, which assumes the high specificity of language. The paper makes the point that the biological machinery of language is neither specifically human nor specifically linguistic. Language emergence would be just one of the far-reaching consequences of a slight modification operated on an ancestral architecture shared with many other vertebrates.

The paper is organized as follows: Section 2 summarizes the main generative arguments for the innate nature of language. Section 3 introduces the Chomskyan conception of language. Section 4 analyzes the evolutionary relationship between animal communication and language. Section 5 centres on human phylogeny, and discusses the usual generative position, according to which language emerged abruptly. Section 6 introduces the computational approach on the prehistoric record and its theoretical underpinnings. Section 7 illustrates this approach with a computational analysis of geometric engravings from the Eurasian Lower and Middle Palaeolithic (*Homo neanderthalensis* and perhaps *Homo heidelbergensis*) and from the African Middle Stone Age (Anatomically Modern Humans; henceforth, AMH). I will show that the computational analysis of those engravings may reveal the kind of language those species were endowed with. Finally, Section 8 discusses the implications of the computational approach; following Balari & Lorenzo (2009, 2013), this section contends that language derives from an enhanced working memory space operating on an unspecific computational system shared with many other animals. That slight change, though, had vast consequences, in the spirit of Evolutionary Developmental Biology (Evo-Devo).

The main arguments for linguistic nativism

Let's consider these words by Karmiloff-Smith (1992, p. 1): "Have you noticed how quite a large number of developmental psychologists are louth to attribute any innate predispositions to the human infant? Yet they would not hesitate to do so with respect to the ant, the spider, the bee or the chimpanzee. Why would Nature have endowed every species except the human with some domain-specific predispositions?". Her words criticize the explanatory framework on human beings that prevailed in the first half of the twentieth century, based on a strict divide between 'nature' and 'nurture'; whereas animals cannot 'escape' from their biology, human behavior would be solely determined by culture. The conception of human beings as a 'tabula rasa' stems from here (see a critical analysis by Pinker, 2002).

However, this view goes against common sense (Lorenzo & Longa, 2003a): our species would be completely different from the rest of species, a kind of 'cultural island' within an animal kingdom full of species-specific predispositions, as widely shown by Ethology. Why should we be 'special' if we have been shaped by the same principles and mechanisms at work on the remainder of creatures? In fact, disciplines like Biology, Developmental Psychology, or Cognitive Science in general have shown that view to be mistaken (see Wilson & Keil, 1999). The same surprise applies to the idea that language is a purely cultural trait, free from any innate support (excepting physiology). As argued for by Anderson (2004), while nobody would deny that animal communication depends on biology, the same idea was (and still is) neglected as regards humans. Why, again, should we be 'special' creatures in this sense?

In the 1960s, Noam Chomsky challenged the traditional view on language by claiming that language is biologically rooted, and belongs to our biological endowment. Since then, many Chomskyan-oriented scholars have adduced a number of compelling arguments for the innate nature of language (see Lorenzo & Longa, 2003a, ch. 2 for an in-depth view). Those arguments are synthesized next.

Species universality

Every human group has complex language, i.e. hierarchically organized (the words of a sentence are not like beads on a string, but show a parts-within-parts structure) and recursive (units may contain other units of the same type: '$_{\text{Sentence}}$[John thinks $_{\text{Sentence}}$[that Helen will come]]'). This is so even for isolated groups, in such a way that "every culture which has been investigated, no matter how 'primitive' it may be in cultural terms, turns out to have a fully developed language, with a complexity comparable to those of so-called 'civilized' nations" (Crystal, 2010, p. 6). For example, genetic studies suggest that Khoisan communities separated from the rest of humankind between 150-90 ka ago, and apparently remained isolated until about 40 ka ago (Behar *et al.*, 2008). However, Khoisan languages do show the same kind of properties as other languages (the alleged exceptionality of the Amazonian language Pirahã, sustained by Everett, 2005, has been strongly questioned by Nevins *et al.*, 2009).

Species-specificity

Only humans have language. Some experiments designed to teach language to nonhuman animals have revealed a certain symbolic capacity, but nothing like syntax. For example, the signing of primates, as shown by Rivas' (2005) deep review, "lack[s] a semantic or syntactic structure in sequences of signs" (Rivas, 2005, p. 415); More on this below.

A neural substrate for language

Although specific details of the neural substrate for language remain unclear, brain imaging techniques have greatly improved the evidence on its neural correlates. Those techniques have identified "Different pathways connecting frontal and temporal cortex" (Friederici, 2009, p. 175), both dorsally and ventrally located, which are crucial for language processing (see Friederici, 2009, 2011; Friederici *et al.*, 2011; Berwick *et al.*, 2013). Interestingly, some pathways, like the dorsal pathway connecting the posterior part of Broca's area with the posterior superior temporal cortex, that "supports core syntactic computations" (Berwick *et al.*, 2013, p. 93), are weak in primates. Some subcortical areas are also relevant (Lieberman, 2000). Therefore, although no compact brain region devoted to language exists, it is nevertheless possible to characterize a 'language organ' (Anderson & Lightfoot, 2002), composed of a set of richly interconnected areas.

Genetic foundations of language

To conduct genetic studies of language is another way of investigating the innate nature of language (Stromswold, 2001). Currently, a great body of evidence indicates that genetic factors influence the proficiency level attained by children and adults in several language components. A number of genes have been discovered which have a relevant role in many types of inherited language disorders, beyond the 'famous' *FOXP2* gene (see Benítez-Burraco, 2009, Di Sciullo *et al*., 2010). Therefore, although no 'language genes' exist (Benítez-Burraco & Longa, 2011, 2012a), several genes are involved in the linguistic phenotype.

A critical period for language

A critical or sensitive period is "A period of time with a distinct onset and offset during which experience can lead to learning by an organism: assumed to be innately programmed and irreversible" (Lust, 2006, p. 93). This period is, thus, a 'temporal window' in which a trait can be acquired through exposure to the relevant experience; however, if such an exposition takes place after the window is closed, the trait will no longer be acquired. The critical period is very important for assessing whether or not a trait is biologically seated, for it restricts the capacity of the environment for modeling organisms. Lenneberg (1967) proposed a critical period for language, which would extend until puberty (for discussion, see Meisel, 2013). An exhaustively documented case study (that of Genie; see Curtiss, 1977) seems to confirm such a period: in spite of years of intensive rehabilitation, Genie was unable to acquire several core components of the syntactic structure.

Native and second language acquisition

Strong differences arise between L1 (native) and L2 (non-native) language acquisition (Bley-Vroman, 1990). They can be summarized as follows: infants acquire their native language effortlessly and unconsciously, and their success is guaranteed in advance (pathologies aside); however, to acquire a second language implies great effort, and the outcomes of the acquisition are very variable. This suggests that while L1 acquisition is eased by an innate support, that support is lacking when acquiring an L2, this difference perhaps being related to the offset of the critical period (see White, 2003; for sign languages, see Mayberry, 2010 and Kegl *et al*., 1999 on the Nicaraguan sign language case).

The 'language acquisition paradox'

According to Jackendoff (1994), while the highly abstract principles of languages have been hotly debated for centuries, children master them in a rapid, spontaneous and effortless way. Jackendoff's claim can be widened by saying that linguistic development is inversely correlated to intellectual development (Lorenzo & Longa, 2003a, ch. 2): the more cognitively immature an individual (i.e. a child), the more facility in acquiring language, and vice versa.

Double dissociation between language and cognition

Disease or injury lead to multiple instances of clear dissociations between language and other cognitive aspects in such a way that we can find a fully developed language and an impaired cognition, and vice versa (see Cromer, 1994; Curtiss, 1994, 2012; Guasti, 2002, ch. 11; Lust, 2006, ch. 5; Tsimpli, 2013; Yamada, 1990). Specially illustrating are cases like the savant Christopher (Smith & Tsimpli, 1995; Smith *et al*., 2011) or the Williams syndrome (Bellugi *et al*., 2000; Musolino *et al*., 2010; Musolino & Landau, 2012). This cognitive specificity of language faces the mental architecture of cognitive non-differentiation argued for by Piaget (Piaget & Inhelder, 1969; see Piattelli-Palmarini, 1980 for an exciting debate between Chomsky and Piaget), and seems to fully support the modularity of mind (Fodor, 1983) and language (Chomsky, 1980), according to which each module derives from innate principles specific to it (see the splendid review by Curtiss, 2012).

How acquisition takes place

Although a degree of individual variation obviously exists, the rhythms and stages of language acquisition are surprisingly uniform across languages. As Kuhl & Meltzoff (1997, p. 7) put it, "Infants acquire language like clockwork. Whether a baby is born in Stockolm, Tokyo, Zimbadwe or Seattle, at 3 months of age, a typically developing infant will coo. At about 7 months the baby will babble. By their first birthday, infants will have produced their first words, and by 18 months, 2-word combinations. Children of all cultures know enough about language to carry on an intricate conversation by 3 years of age". Aspects like background variation or intelligence do not break that basic uniformity. In addition, sign languages follow the same developmental path; in spite of their different modality, they show the same timing and stages of acquisition (Petitto, 1997; Mayberry & Squires, 2006).

The role of 'motherese'

In the seventies, some empiricists claimed that motherese, the speech specifically directed to babies, made nativism unnecessary, for motherese (1) was universal (Ferguson, 1977), and (2) offered "easy examples to little minds" (Snow, 1977), thus avoiding that children suddenly became exposed to language complexity. However, the alleged universality turned out to be false: many cultures lack motherese (Pinker, 1994 and references therein), and adults do not address children until the point at which children themselves can converse. If, as argued by empiricists, motherese is crucial for language acquisition, in cultures with motherese children would be expected to acquire language more quickly than in cultures lacking motherese. This prediction, though, is not borne out: the rhythm is the same (Crago *et al.*, 1997). Furthermore, in some aspects motherese does not ease syntactic development, but makes it harder (O'Grady, 1997, chs. 12-13): core phenomena like recursion only appear in complex sentences, "the very type of structure that is rare in caregiver speech" (O'Grady, 1997, p. 253).

The poverty of the stimulus

This argument relies on the difference between the input and the output of the acquisition process. Its basic tenet is that the intricate linguistic knowledge any normal child arrives at strongly contrasts with the degenerate and deficient nature of the data she comes across. The mismatch suggests that a relevant part of that knowledge cannot derive from experience, but is innate (see Piattelli-Palmarini & Berwick, 2012). More specifically, nativism characterizes three types of poverty (Hornstein & Lightfoot, 1981; Lightfoot, 1999): (1) degeneracy: stimuli are deficient because they contain both grammatical and ungrammatical sentences (utterances with pauses, fragments, etc.), but children are not informed about their un/grammatical status; (2) finiteness: stimuli are deficient because children are exposed to a finite array of data, but they can deal with the infinite array of the sentences a language consists of; (3) partiality: stimuli are deficient because "People attain knowledge of the structure of their language for which no evidence is available in the data to which they are exposed as children" (Hornstein & Lightfoot, 1981, p. 9). The crucial sense of poverty is (3): (1) and (2) do not deny that experience is available, although it is degenerate; however, (3) "says not that relevant experience is degenerate but that in certain areas it does not exist at all" (Lightfoot, 1999, p. 61). Box 1 offers an example of sense (3).

Conclusion

The summarized arguments suggest that language is an innate trait of the human species. Accordingly, Chomsky has repeatedly claimed that language should be thought of as a branch of human biology (Chomsky, 1975, 1980, 1988, etc.), which 'grows' as other human organs and organic systems do during a given critical period: "The child's language 'grows in the mind' as the visual system develops the capacity for binocular vision, or as the child undergoes puberty at a certain stage of maturation. Language acquisition is something that happens to a child placed in a certain environment, not something that the child does" (Chomsky, 1993, p. 29). The innate principles responsible for language acquisition make up the Universal Grammar, "the genetic equipment that makes language growth possible"

BOX 1. Partiality of the data: structure-dependence

Language is produced/received linearly, but underlying the linear arrangement, a hierarchical structure exists which is not directly perceptible in the input. How do children come to master hierarchical structure?

Hierarchy has been a recurrent issue for illustrating the sense (3) of the poverty of stimulus (Chomsky, 1968, 1975, 1980, 1988; Boeckx, 2006) through the so-called structure-dependence property: rules of language are structure-dependent (they operate through hierarchical structure) instead of being structure-independent (if so, they would operate through linear structure). Interrogative sentences illustrate. Let's consider:

The man is happy / The man is German

The interrogative version is formed with the movement of the verb from its original position (marked with a dash below) to the initial one:

Is the man ___ happy? / Is the man ___ German?

The most obvious hypothesis for generating these sentences is to discover the first appearance of the verb, and to displace it to the beginning. This hypothesis would be structure-independent, for it relies on arithmetic criteria operating on the linear structure. The hypothesis is very simple, and it functions quite well for the simple sentences the child is exposed to. However, it does not work for more complex instances like:

The man who is happy is German ⇒ *Is the man who ___ happy is German?

The ungrammatical nature of the sequence derives from the fact that for the interrogative structure to be formed, the first verb is irrelevant; the key verb is the main verb, placed after the subject, i.e. the hierarchically most prominent verb, be it the first or the fourth verb. For discovering the main verb, a much more complex rule has to be applied, which makes an abstract computational analysis of the sentence in order to discover a verb in a given structural position. Accordingly, this rule is structure-dependent: it operates on the hierarchical structure, not on the linear one.

However, at least in cultures with motherese, children are not exposed to complex sentences that would permit them to infer the hierarchical rule (Legate & Yang, 2002). The linear rule fits in well with the data of the input, mainly "sentences without embedding" (Crain & Pietroski, 2001, p. 163). Despite the absence of the relevant experience, the child knows perfectly that structure-dependent rules are the only option; even 3 years old children do not consider the linear rule at all (Crain & Nakayama, 1987; Crain, 1991; Crain & Thornton, 1998, ch. 20; (for recent critiques of this issue and a rebuttal of these critiques, see Berwick *et al.*, 2011, 2012).

If that knowledge cannot be inferred from the input, the obvious assumption is that it derives from an innate constraint, part of the biological endowment for language. This kind of innate constraint restricts the state space, thus avoiding a brute force search: the child does not have to consider linear hypotheses, but just hierarchical. This makes language acquisition a more restricted, robust and rapid process.

In addition, the poverty of the stimulus is also shown by the fact that infants do not need to have access to a structured linguistic input for developing language. In the absence of a grammatical system, they themselves develop it. As regards oral languages, children create systems with grammatical regularities (creole languages) from systems lacking syntactic structuring (pidgin varieties) (see Bickerton, 1990, and especially Adone, 2012). The same applies to sign languages: "Deaf children whose hearing losses prevents them from acquiring the spoken language that surrounds them, and whose hearing parents have not exposed them to a conventional sign language, invent gesture systems, called homesigns, that display many of the properties found in natural language" (Goldin-Meadow, 2007, p. 417; see also Kegl *et al.*, 1999). This makes sense if development is guided by innate mechanisms.

(Lightfoot, 1999, p. 65). Given a minimum of experience, these principles are triggered, thus making it possible to attain the steady state of knowledge of every native speaker. Accordingly, the role of experience is to activate the innate linguistic principles. The next section clarifies what the innate component of language is.

The Faculty of Language as a biological object

To begin with, the notion of 'language' is ambiguous, as it covers many different aspects: historical, social, cultural, etc. However, the Chomskyan biolinguistic approach is not concerned with these aspects. To avoid terminological problems, I will refrain from using 'language', and will use instead 'Faculty of Language' (henceforth, FL) to refer to language as a biologically seated capacity that evolved in human phylogeny. I will briefly characterize its architecture, for it is such an architecture that has to be explained evolutionarily.

FL (i.e. syntax) may be defined as a natural computational system that resides in the mind/brain of all members of the human species, pathologies aside. Two terms of this definition are to be highlighted: 'computational' means that FL is a system of information processing based on the capacity for manipulating mental elements (Chomsky, 1980, 1988, 1995, 2000, 2002, 2005; Hauser *et al.*, 2002; Berwick & Chomsky, 2011); 'natural' implies that FL is a biologically rooted mental organ (Anderson & Lightfoot, 2002) restricted to our species (at least, currently). To sum up, FL is an innate property.

From the view of mental architecture, FL is a bridge faculty, which connects two different systems: the Articulatory-Perceptual system (henceforth, A-P), in charge of the workings of our visual, oral, gestural and auditory activities, and the Conceptual-Intentional system, (henceforth, C-I), responsible for the production of intentional thoughts and attitudes on and about the world. Both capacities are independent: on the one hand, not every thought needs to be externalized; on the other, we can produce sounds without any associated meaning. According to its status of bridge theory, FL provides the channel by which representations of A-P and C-I systems (i.e. sounds/gestures and meanings) become accessible to each other. Therefore, FL, or to put it equivalently, the computational system, takes elements from the lexicon and "generates an infinite array of hierarchically structured expressions" (Chomsky, 2010, p. 45), thus giving rise to the property of discrete infinity (i.e. an unlimited combinatorial capacity), for the number of sentences of a language is infinite. Although lexical items are finite, and the same applies for the grammatical rules languages make use of, the rule-based combination of lexical pieces gives rise to infinity. This property is enabled by recursion, which makes it possible to embed constituents within constituents of the same type (i.e. sentences within sentences, like in $_S$[John says $_S$[that Jennifer thinks $_S$[that…]]], or phrases within phrases).

FL connects to the A-P and C-I systems through two interfaces: an external sensorimotor interface with the A-P system, in charge of the exteriorization of the expressions generated by FL (production) and of their interiorization (perception), and an internal conceptual-intentional interface with the C-I system, which links the mental expressions with the semantic and pragmatic interpretation, concepts, reasoning, etc. Each expression generated by FL receives an interpretation in each interface.

As advanced above, the main feature of FL is its unlimited combinatorial power, independent from the specific acquired language. This means that it is important to distinguish between the process of acquiring a first language (Italian, English, Turkish, etc.) and the innate developmental process leading to FL in an individual. The development of FL is a precondition for the acquisition of any human language. When the process of language development (due to the interplay of three factors; see Box 2) ends up, the individual possesses a mental grammar or I(nternal)-language (a state of FL) by which an infinite array of sentences can be generated and interpreted.

The following sections concentrate on the evolutionary perspective, by discussing how the architecture of FL could come into being.

Language precursors in nonhuman animals?

Animal communication and human language

Whereas nonhuman animals were traditionally considered to be only endowed with stimulus-response mechanisms, the intensive study of animal communication in the last few decades has revealed highly complex communicative behaviors (for a survey, see Hauser, 1996; Longa,

BOX 2. The Minimalist Program and the three factors of language development

Earlier generative models contended that language development derived from two factors: genetic endowment and experience. The genetic endowment for language (Universal Grammar) was supposed to be very rich, and specifically linguistic. Importantly, the current generative model, the Minimalist Program, brings a third factor to the fore: "Principles not specific to the faculty of language" (Chomsky, 2005, p. 6). This third factor is composed of several subtypes, like principles of structural architecture, developmental constraints (canalization), and, especially, "principles of efficient computation, which would be expected to be of particular significance for computational systems such as language" (Chomsky, 2005, p. 6). This last subtype favors the minimization of computational complexity.

According to minimalism, FL is an optimal system, for it directly connects the A-P and C-I modules. This is the Strongest Minimalist Thesis: "Language is an optimal solution to legibility conditions" (Chomsky, 2000, p. 96). If the thesis were proven to be right, FL would have a minimal structure, the simplest one, and many of its mechanisms would derive from conditions of efficient computation which 'come for free' (i.e. are not pre-specified by the genes), in a similar sense to that used within sciences of complexity (Longa, 2001). This leads to the elimination of the purely linguistic principles of Universal Grammar: given their high specificity, those principles 'hindered' the direct relationship between sounds and meanings. Therefore, there is no need to 'translate' between FL and the two adjacent modules (A-P and C-I): thought is directly externalized. It is for this reason that minimalism implies "shifting the burden of explanation from the first factor, the genetic endowment, to the third factor, language-independent principles" (Chomsky, 2005, p. 9).

The elimination of domain-specific principles of Universal Grammar means abandoning the genotypic conception of innate features, which prevailed within Neo-Darwinism, and to assume instead a phenotypic conception (Longa & Lorenzo, 2008) in agreement with developmental biology. See Longa & Lorenzo (2012) and Lorenzo & Longa (2003b, 2009) for an innate approach to FL (i.e. the computational system) that does not rely on the genetic level (although the two interfaces and what these interfaces connect to still are in the domain of genetics; see below).

2012; Oller & Griebel, 2004). Several species show truly referential signals that refer to aspects in the world, like danger (i.e. predators) or food (Seyfarth *et al.*, 1980; Evans & Evans, 1999, 2007). Some of those signals make up complex systems, like that of bees (von Frisch, 1967; Dyer, 2002). Furthermore, the signals of some species not only indicate the type of predator, but simultaneously encode other indications: location of the threat (Cäsar *et al.*, 2012), urgency of the situation (Manser *et al.*, 2002), specific characteristics of the predator (Slobodchikoff *et al.*, 2009), predator behavior (Griesser, 2008), or even predator type, size and degree of threat simultaneously (Templeton *et al.*, 2005). In a similar way, food signals of some species indicate specific types of food (Bugnyar *et al.*, 2001; Slocombe & Zuberbühler, 2005).

Surprisingly, some animal communication systems possess a hierarchical-combinatorial structure, which somehow resembles that of language, for they are arranged according to successive levels of structure, like notes, syllables, or phrases: for example, bird songs (see Berwick *et al.*, 2011, 2012; Bregman & Gentner, 2010) and calls (Hailman *et al.*, 1987), bats (Bohn *et al.*, 2009), tamarins (Cleveland & Snowdon, 1982), hyraxes (Kershenbaum *et al.*, 2012), gibbons (Mitani & Marler, 1989) or whales (Payne & McVay, 1971).

Despite the great complexity of animal communication, its properties are very different from those of human language. Animal communication is restricted to aspects related to biological needs (mainly, food, danger, courtship and mating), but language makes it possible to communicate any event, even an unreal one (for this reason, caution!: language is much more than a merely communicative system). This does not amount to saying that animals lack other concepts; they do possess sophisticated concepts (see below), but most of them cannot be shared with conspecifics. As Fitch (2010, p. 148) puts it, "animals have surprisingly rich mental lives, and surprisingly limited abilities to express them as signals". This suggests that a barrier exists between cognition and communication in animals. Such a barrier is absent in humans: everything we can represent can be expressed to others (either by language alone or by language supplemented with images, graphs, equations, etc.). Furthermore while animal communication is restricted to 'the here and now' (Hauser *et al.*, 2002, p. 1576), through language humans may refer to past or future events.

In addition, although animal signals are linked to mental concepts that are between the sensory input and the response to the signal, the signal triggers a unique response: for example, when a monkey hears an alarm call, the only available response is to escape. Therefore, a functional or instrumental association exists (the concept of the predator is conflated with danger). Language, though, lacks any functional association: if you hear 'leopard' you will not escape in most contexts! This is so because language evokes properties, not reactions (Bickerton, 1990).

It should also be highlighted that animal communication depends on sensory perception (experience), but language permits us to refer to any aspect in the absence of prior experience. This leads to a key feature: language is a powerful representational system, according to which any concept may be represented (and expressed): concepts related to physical objects (table, leg), abstract concepts (justice, dishonor, malice) o even unreal ones (fairy, phantom, hobbit, longitude, latitude). That representational power greatly increases by means of syntactic combinations. Therefore, "We create worlds with language" (Jerison, 1985, p. 31). To sum up, language builds our reality, and, paradoxically, also constructs unreality. This means that language provides cognition with a great flexibility (Dennett, 1996): through language any situation may be conceived, and thus it has a key role in human creativity.

Although animal communication exhibits both symbolism and combinatorial nature, no animal system combines both levels: if an animal system exhibits symbolism, it lacks a combinatorial nature, and vice versa. This means that, despite their resemblance with language, animal combinatorial systems are very different to language: because "birdsong lacks semantics and words" (Berwick *et al.*, 2011, p. 113), "birdsong lacks nearly all the chief attributes of human language" (Berwick *et al.*, 2012, p. 23). The same applies to the other animal combinatorial systems (those of bats, whales, etc.).

Because of the vast differences between animal communication and language, Chomsky (1968) argued that language is a true biological emergence, which can hardly be explained through a usual process of Darwinian descent with modification from animal communication. However, a question becomes relevant: is language an overall emergence, which cannot receive any kind of continualist explanation based on natural selection? Not really, as shown below.

A more fine-grained approach

Hauser *et al.* (2002) propose a divide between Faculty of Language in the broad sense (henceforth, FLB) and in the narrow sense (FLN) as a useful methodological tool for guiding research projects on language evolution. According to those scholars, language is not a monolithic trait, but something like a mosaic, composed of different aspects evolutionarily superimposed. Therefore, in order to investigate its origins, language should be divided up into its different components. The aforementioned divide makes it possible to analyze the evolutionary history of each component, thus aiming at determining which components are shared with other species and which components are not. The features suspected of being inherited unchanged from a common ancestor or subjected to minor modifications would be part of FLB, whereas the qualitatively new features (specifically human and specifically linguistic) are said to be part of the FLN (therefore, Hauser's *et al.* framework relies on a fully comparative method, not restricted to primates or even to mammals; see Fitch, 2011). According to the divide, FLB gathers all the capacities necessary for language which are neither specific to language nor to humans, whereas

FLN covers those capacities unique to language and to humans.

From the comparative evidence, Hauser *et al.* (2002, pp. 1572-1573) suggest that while main mechanisms of the A-P and C-I modules have clear homologues in nonhuman animals, quite the opposite applies for the computational system: this system is the only evolutionary novelty and the only component of FLN (of course, such a contention would be modified if proven mistaken). A second and stronger contention of Hauser *et al.* has to do with the specific contents of FLN: the only candidate to be included within FLN is recursion, i.e. the recursive procedure the computational system of human language makes use of, with its open-ended generativity based on the structural embedding of hierarchically organized phrases. With their own words, "we suggest that FLN —the computational mechanism of recursion— is recently evolved and unique to our species" (Hauser *et al.*, 2002, p. 1573). This implies that only FLN (not FLB) would require special (i.e. not shared) explanations (Fitch *et al.*, 2005, p. 181) (for a criticism of the 'recursion-only' hypothesis, see Pinker & Jackendoff, 2005; see also the reply by Fitch *et al.*, 2005).

Actually, animal research has widely shown that many mechanisms of the A-P system are shared with nonhuman animals (see the reviews by Hauser & Fitch, 2003, Yip, 2006 and Samuels, 2012). As regards speech production, several phenomena traditionally considered to be uniquely human have recently been shown to be shared: for example, according to Lieberman (1991, 1998), the lowering of the larynx, uniquely experienced by our species, was a key development for speech, but papers like Fitch & Reby (2001) or Fitch (2002) show that claim to be untenable. Other central aspects are shared as well: communication with formants (Fitch, 1997), complex vocal imitation (Janik & Slater, 1997) or the evolutionary bases of the syllable (MacNeilage, 1998), which derive from an ancestral capacity linked to chewing. The same applies for speech perception: different animals share with us the capacity of categorical perception over human speech sounds (i.e. to divide a continuum of sounds into discrete units; see Hauser, 1996), the perceptual magnet effect, by which prototype and non-prototype sounds are discriminated (Kluender *et al.*, 1998), the discrimination between sentences of two different languages from their rhythmic differences (Ramus *et al.*, 2000), or the perception of statistical regularities based on transitional probabilities (Hauser *et al.*, 2001). All of this means that "The abilities that underlie human phonological competence are found scattered across a wide range of species, though no single species besides ours may possess all of these abilities" (Samuels, 2012, p. 313). The foundations of speech are very ancient, and did not evolve for language *per se*.

A similar situation arises for the concepts the C-I system is composed of (do not conflate with words). Animals do have a complex mind, and their mind possesses sophisticated conceptual representations, unsuspected a few decades ago (for a survey, see Carruthers, 2006, ch. 2; Hauser, 2000; Hurford, 2007; Pepperberg, 1999). For example animals can categorize, an operation underlying concept formation, and presupposing capacities like induction, generalization or abstraction. Accordingly, "Possession of words is not a necessary criterion for identifying possession of concepts" (Hurford, 2007, p. 10). In addition, animals show many other capacities like number sense, natural geometry (orientation and displacement according to geometric cues) or navigation (a capacity which gives rise to highly abstract cognitive maps). If we also consider the acquisition of a conceptual structure by trained primates, the conclusion can be reached that homologues of the C-I system do exist, although the great majority of its contents cannot be expressed to conspecifics.

To summarize, "FLB as a whole thus has an ancient evolutionary history, long predating the emergence of language" (Hauser *et al.*, 2002, p. 1573). However, the search for a syntax-like system in nonhuman animals, whether wild or trained, has been fruitless (see Box 3). This suggests that FL (i.e. the computational system) is not shared with nonhuman animals; rather, it emerged in the course of human evolution. The next section approaches this issue.

Box 3. Primates and sign languages

Many experiments tried to teach language to other species, especially primates. Because primate natural communication mainly relies on gestures, a number of experiments used American Sign Language (ASL) (see Rivas, 2005; Wallman, 1992 for reviews). According to those who conducted them, the results were successful: primates allegedly produced and understood sentences in the gestural channel. However, that assumption was built on the unwarranted premise that sign languages were considered degenerate versions of oral languages, formed with rudimentary gestures with meaning.

However, sign languages are as complex as oral languages (see Anderson, 2004, ch. 9; Emmorey, 2002; Brentari ed., 2010; Janzen, 2007; Pfau *et al*. eds., 2012). For example, they have a gestural equivalent of phonology: signs derive from combining several parameters none of which is meaningful, like handshape, plane of movement, place of articulation, orientation, contact region, etc. Therefore, sign languages have duality of patterning. The notion of syllable is also relevant in sign languages (van der Kooij & Crasborn, 2008). Furthermore, they express many morphological categories (tense, aspect, agreement, etc.) and show productive processes of word formation (compounding, derivation, inflection). The same applies for syntax: sign languages have many syntactic procedures (specific facial configurations becoming relevant) from which complex hierarchical structures result (see Neidle *et al*., 2000).

All of that means that "the meaning of sign language sentences does not come for free by simply looking at signs as if they were pictures" (Mayberry, 2010, p. 283). Sign languages are a combinatorial system that gives rise to discrete infinity, much like oral languages.

However, the signs taught to primates lacked were restricted to their lexical meaning, lacking any kind of grammatical categories or syntactic procedures. When primates' interpretation of sentences depended on grammatical elements, the results were poor, for those elements were ignored. The sentences displayed by primates lacked productivity (i.e. a rule-based nature; see Yang, 2013), and consisted of a few elements linearly arranged, without any trace of hierarchy. In addition, the signs produced by primates were indivisible. This leads to the conclusion that the alleged acquisition of ASL by primates "is based on the myth that ASL is a crude system of pantomimes and gestures rather than a full language with complex phonology, morphology, and syntax" (Pinker, 1994, p. 337). Primates were taught a pidgin-like variety lacking any kind of structure (Wallman, 1992, p. 105). To summarize, the experiments revealed that primates were able to learn a symbolic system, not a linguistic one.

Faculty of Language and human evolution

How simple is Faculty of Language? On the nature of the explanandum

As advanced above, because FLN lacks any kind of homologues in animals, the computational system had to emerge during human evolution. That said, the relevant question is whether FLN evolved according to a gradual and adaptive process through different hominid species, or was instead an evolutionary outcome specific to AMH. Before approaching this issue, it is necessary to characterize what the computational system consists of, for its nature will determine the range of possible hypothesis about its evolution.

From the view of the Minimalist Program (Box 2), FL (the computational system) is mainly reduced to a unique operation, called Merge, which operates recursively and gives rise to hierarchical structures (see Hornstein *et al.*, 2005, pp. 200-212). This operation, similar to an algorithm (Boeckx, 2010, p. 141), merges two syntactic objects (lexical items, affixes, or groups of lexical items) into a new object, one of the two merged elements becoming the head of the resulting structure. Obviously, for two objects to merge, their features need to be compatible; for instance, combinations like 'a the' or 'smile break' would be rejected by the interface with the C-I system.

As an illustration, a sentence like 'John will grow the tomatoes' would derive from the following operations (specific details are omitted):

- Merge 1: {the, tomatoes}
- Merge 2: {grow, {the tomatoes}}
- Merge 3: {will, {grow the tomatoes}}
- Merge 4: {John, {will grow the tomatoes}}

Therefore, FL is very simple; its apparent complexity basically derives from a simple operation, the conditions of which are simple as well (Longa *et al.*, 2011, p. 599; for the more delicate issues concerning the working of the Labeling Algorythm, see Chomsky, 2013):

1) Binarity (see Kayne, 1994): Merge combines two elements instead of three, four, etc., thus triggering binary branching. This greatly reduces the computational complexity (see Box 4).
2) Asymmetric labeling: the outcomes of Merge become identified with one of the two merged elements, and not with both of them or with a different one: the projection of a verb produces a verbal phrase, etc. One of the two merged elements is either, ideally, extracted from the lexicon as a head, or is treated as the head in further operation of binary Merge in the resulting derivation. Therefore, asymmetric labeling implies the property of headedness (endocentricity).
3) Structural preservation: each successive application of Merge preserves the structure obtained so far. This condition is computationally efficient, for it leaves the two syntactic objects unaltered (no-tampering condition). For example, structural preservation dictates that, once labeled, the head remains what it is for the rest of the derivation.
4) Unboundedness: Merge operates in an unlimited way. Thus, no syntactic constraint applies to restrict the derivation to a maximum number of recursions (the limitations can only be due to short-term memory, attention, and similar).

Those conditions suggest that FL seems to be optimal from the view of the Strongest Minimalist Thesis (Box 2): FL is as simple as possible, perhaps made up by just one basic operation, the formal conditions of which are also simple and generic principles of efficient computation. In fact, these principles seem to 'come for free' spontaneously, without any need for specific stipulations in the form of genetic instructions; they may arise from third factor conditions (see Boxes 2 and 4). Those conditions point to the kind of processes sciences of complexity is concerned with (see Longa, 2001): optimal self-organization of forms and simplicity and generality of the generative processes (Box 4).

Therefore, Merge, at the heart of FL, is the only component of language specifically emerged in evolution, the only specifically linguistic and specifically human component. Combined with the prior infrastructure, and with the appearance of the lexicon, Merge led to language emergence. This is the very idea underlying Hauser *et al.*'s (2002) framework: a specific novelty linked to pre-existent components.

This proposal fits in well with evolutionary dynamics, finely characterized by Jacob (1977): evolution is a 'tinkerer' that works by adding slight modifications on previous systems through a recycling task: "Evolution does not produce novelties from scratch. It works on what already exists" (Jacob, 1977, p. 1164). Hauser *et al.*'s (2002) proposal combines evolutionary recycling and evolutionary novelty, a blending central in every evolutionary process (Marcus & Fisher, 2003). It is interesting to note that according to Evo-Devo (see Box 8), new species do not presuppose new genes (Carroll, 2005; for the hypothesis of the Universal Genome, see Sherman, 2007). In this way, the task of explaining language evolution becomes easier, for it means adding a specific novelty (Merge) to prior components. For that reason, "The less attributed to genetic information for determining the development of an organism, the more feasible the study of its evolution" (Chomsky, 2007, p. 4). As suggested by Lorenzo (2008), assuming a slight specific novelty (whose formal conditions can be independently accounted for by third factor effects) frees the explanation from the need to link that novelty to homologues or intermediate gradual states.

To sum up, Gazzaniga (2008, p. 2) writes that "most human activity can be related to antecedents in other animals", although at the same time "we are very different from other animals". His words may also characterize the proposal by Chomsky and associates: a little change on a prior infrastructure

Box 4. Physical laws and self-organization: the third factor

Cherniak (2009) offers an intriguing example about computational neuroanatomy that nicely illustrates the type of processes related to the third factor, those processes resembling the nature of the formal conditions exhibited by the Merge operation. Whereas the two major alternatives on the treatment of the divide 'nature-nurture' have been (1) the genome or (2) the external environment, Cherniak suggests a third alternative, nongenomic nativism.

Cherniak analyzes the connection costs in nervous systems, a computationally complex problem, which cannot be pre-specified in the genome. Although the connection resources are limited, the brain has finely minimized the connection costs between neurons, in such a way that optimization emerges in the development of neural connections in several levels of the nervous systems. Such an optimization produces "the best of all possible brains" (Cherniak, 2009, p. 115). Interestingly, this scholar shows that optimization derives from physical principles, and leads to self-organization of biological matter through structures that, in spite of being innate, do not lie in the genome and do not require the workings of the genes. Hence nongenomic nativism, whose transfer to the scope of third factor is easy.

Interestingly, Cherniak's research suggests that binary structure robustly arises in the connections established by both dendrites and axons, in spite of not being contained in the genes. Therefore, binary branching in biological tree structures seems an optimal solution. This also applies to the binary branching, via Merge, of linguistic tree structures, which in the same way suggest a nongenomic nativism.

led to the emergence of FL, thus producing great differences with regard to animal thought and communication. As opposed to the Neo-Darwinian framework, based on a strictly gradual evolution, the aforementioned view contends that a minor modification operating on a previous base may produce an abrupt leap (Berwick, 2011), something like a phase transition.

The emergence of Faculty of Language and 'evolutionary asymmetry'

The point has been made that FL is very simple, for the computational system is reduced to the Merge operation. Because its formal conditions derive from third factor effects, those conditions need not be explained: they are default solutions arising in computational systems. It is just Merge that should be explained. From this view, what about the evolutionary event that gave rise to Merge?

In the last decade, Chomsky has suggested two different answers to that question: (1) FL could emerge as the consequence of the contact between the A-P and C-I systems, previously and independently evolved, or (2) FL could first arise in the domain of thought, and was subsequently exapted to language. Chomsky defended option (1) at the beginning of the 2000s (Chomsky, 2000). However, more recently (Chomsky, 2007, 2010) this scholar has favored option (2), which assumes an evolutionary asymmetry, as the exposition will make clear.

Although "There are of course no definite answers" (Berwick & Chomsky, 2011, p. 26) about the appearance of FL, Chomsky suggests that the simplest speculation about an evolutionary scenario should run as follows: Merge could arise through some rewiring of the brain produced by a genetic event, "presumably a small mutation" (Chomsky, 2007, p. 14; see also Chomsky 2005, pp. 3 and 12; Chomsky, 2009, p. 29; Chomsky, 2010, p. 58), given the simple architecture of FL. However, it is important to emphasize that, according to option (2), Merge firstly arose in the domain of thought, giving rise to something like a language of thought (i.e. an inner language). That mutation took place in an individual pertaining to some AMH small breeding group from East Africa from which we are all descendants, this claim deriving from the essential uniformity of FL in the species. The slight rewiring of the brain from which unbounded Merge emerged led to a substantial modification of the simple system of thought existing so far, based on elementary schemata, and produced an "explosive growth of the capacities of thought"

(Chomsky, 2007, p. 14). That growth gave rise to the possibility of generating an infinite array of internal expressions made up from (already available) lexical items. The individual referred to above "had many advantages: capacities for complex thought, planning, interpretation, and so on" (Chomsky, 2010, p. 59). Then, the mutation would be transmitted to the offspring, also as an internal capacity, in such a way that it began to proliferate among the group.

When that internal capacity spread over the members of that population, "there would be an advantage to externalization" (Chomsky, 2010, p. 59). Perhaps with a mutation, such an internal capacity was linked as a secondary process to the A-P system in charge of externalization, intact for hundreds of thousands of years. Obviously, this process was related to second factor conditions (environment). When the complex language of thought became externalized, FL in its current sense emerged.

To summarize, in Chomsky's opinion three main stages were involved: (1) a simple system of thought, in which (2) Merge arose at a given point, thus a linguistically structured system of thought being developed (by which the property of discrete infinity was available), but still unable to be externalized; finally, (3) that system of thought becomes externalized, and gives rise to FL, the specifically linguistic and specifically human component of human language. Even although Merge first appeared in the system of thought, the fact that it became linked to externalization and originated FL means that "Merge falls within UG [Universal Grammar]" (Chomsky, 2007, p. 7), for there must exist a genetic instruction to use Merge for generating linguistic expressions satisfying the interface conditions. Given that the Universal Grammar includes those elements specific to FL (and its interfaces), the conclusion can be reached that FL is not just a specifically human capacity but also a specifically linguistic one (but see the last section).

According to Chomsky, an evolutionary asymmetry may be perceived between the two interfaces of FL (Chomsky, 2010, p. 55). If we consider that the previous stage to FL was an internal language of thought, this means that the interface of FL with the C-I system is primary, but the interface with the A-P system (related to externalization) is secondary (although by no means crucial for language). FL exhibits an optimal relation with the C-I system, as shown by the formal conditions of Merge related to efficient computation that were discussed earlier. In fact, it is not necessary to highlight a connection between thought and language: language is just externalized thought (Longa *et al.*, 2011). From this view, there is only one internal language in the species, in charge of generating the expressions of the language of thought.

However, externalization does not hold the same relationship with FL. That externalization is far from an optimal nature is evidenced by the fact that it causes humans to express common internal thoughts differently, according to the very disparate mechanisms (case, aspect, agreement, etc.) languages make use of; this secondary process reveals the evolutionary asymmetry, as reinforced by the fact that language is even modality-independent (oral or gestural).

This leads to the question of why there are so many languages (both oral and gestural), a fact that "seems curious, and a violation of the spirit of SMT [Strongest Minimalist Thesis]" (Chomsky, 2010, p. 60). The aforementioned asymmetry makes it possible to provide a reasonable answer: the great variation related to externalization suggests this phenomenon is not to do with the (biological) evolution of language, but with historical and cultural processes, these processes being highly variable, and producing heterogeneous results. Therefore, while the computational system is essentially uniform across the species, the phonological and morphological processes that convert internal syntactic objects into objects accessible to the A-P system are very different from each other. Interlinguistic variation derives from the disparate solutions to how internal syntactic representations surface in the form of sentences (Berwick *et al.*, 2013, p. 92). To sum up, the solutions to externalization, which were responsible for the great current linguistic variability, are not related to evolutionary change, but just historical change (Chomsky, 2010, p. 61).

In addition, the said asymmetry illustrates a key idea of Chomsky's thought on language evolution quite well: FL did not emerge linked to communication, for communication was a secondary process, derived from externalization. Many scholars fully assume that a selective pressure towards more efficient communication was the driving force in language evolution. Obviously, language is used to communicate thoughts, but the important point is that language is also used for many other functions: to joke, lie, talk to oneself, express thought, among many other purposes any reader can imagine. Therefore, "The functions of language are various" (Chomsky, 1980, p. 230; see Lorenzo, 2008). If one function had to be emphasized, "the overwhelming use of language is internal—for thought" (Berwick & Chomsky, 2011, p. 26). This makes sense as regards the optimal relation of FL with C-I. Therefore, any approach mainly based on communication may be "seriously misguided" (Chomsky, 2010, p. 61; see also Balari & Lorenzo, 2010).

A last topic to be placed on the agenda is the origins of the lexicon, the material on which Merge operates. However, we are still in the dark as to the process by which lexical items could arise (in fact, for Chomsky, 2010, p. 57, it is even difficult to unravel whether lexical items and concepts are different entities; see Boeckx, 2011 for the opposite contention, according to which concepts and lexical elements are clearly dissociated). The main difficulty when approaching the emergence of the lexicon is that although conceptual structures may be attributed to primates and other animals, the lexicon seems a specifically human endowment: lexical items (and perhaps human concepts) are much more abstract elements than animal concepts, as acknowledged by Berwick & Chomsky (2011, p. 39): "even the simplest words and concepts of human language and thought lack the relation to mind-independent entities that appear to be characteristic of animal communication". That is, while animal concepts seem to keep a referential relationship with objects or events of the world (food, danger, etc.), in humans the one-to-one relationship between concepts/words and objects does not exist at all; we do not have "names for things" (Berwick *et al.*, 2013, p. 93), even for the simplest concepts. For example, an apparently simple concept like 'book', which seems to point to a real referent, may nevertheless apply to a vast range of situations which reside in the mind and not in the environment: it can refer with the same easiness to books that no longer exist, or to books that have never existed. The conclusion is that lexical items "raise serious challenges for evolutionary analysis" (Berwick *et al.*, 2013, p. 92). Anyway, it is reasonable to assume that the bundles of articulated thought which are the atoms of computations, related to the lexicon, derived from third factor conditions, i.e. not specifically related to language, although it is not possible to characterize them (Longa *et al.*, 2011).

When did Faculty of Language emerge? What hominid species possessed it?

For obvious reasons, a question of special interest is when the little modification that produced FL emerged. Put equivalently, was FL an evolutionary outcome restricted to AMH, or did other hominid species possess it as well? The previous section anticipated the answer: according to Chomsky and mainstream Generative Grammar, FL is an evolutionary result directly linked to AMH. This amounts to saying that "language has appeared on earth quite recently" (Berwick & Chomsky, 2011, p. 20). More specifically, the emergence of FL may be dated within a narrow evolutionary window, about 100-50 ka (Chomsky, 2010, p. 58). The reason for that dating is not unknown to Paleoanthropology, for many scholars contend that the proxies of modern behavior arise within that narrow timeframe, first in Africa and then in Europe, including many instances of symbolism (many forms of art, ornaments, engravings, burials with offerings, music, etc.), unprecedented technology, or complex social practices, among other aspects.

Those proxies would be a visible effect (although not a linguistic one) of the

Box 5. Language and cognitive flexibility: the prehistoric techno-complexes

Because language enables great cognitive flexibility and creativity, and makes it possible to virtually explore every kind of mental model, the overall static or dynamic nature of a culture may be a relevant proxy about the type of communication a species was endowed with: FL would hardly be expected to exist in an overall static culture. This criterion may be applied to the analysis of several hominid cultural traditions (see Balari *et al.*, 2008, 2013, and Longa, 2009). The static nature in overall terms of the prehistoric techno-complexes previous to AMH is well established, in such a way that "innovations, once established, have tended to persist for long periods of time" (Tattersall, 2010, p. 195).

The first techno-complex, Oldowan (2.6 Ma) is based on a chopper industry that does not shape the stone cores. Oldowan reveals a slow pace of progress (Ambrose, 2001, p. 1752; Klein, 2009, p. 256); in fact, it hardly shows relevant improvements for more than 1 Ma. The same applies to the Acheulean techno-complex (1.65 Ma), in which cores are carefully carved and symmetrically shaped, as evidenced by bifaces. The basic design of Acheulean technology remained nearly unchanged for about 1 Ma: "Acheulean assemblages separated by tens or hundreds of thousands of years commonly differ little if at all" (Klein, 2009, p. 378; see also Ambrose, 2001; Mithen, 1996, ch. 7). Recent remarks about two Acheulean periods for biface carving, bifaces of the second period being more symmetric and thinner (Klein & Edgar, 2002, pp. 108-109 and 141-142; Klein, 2009, pp. 379-380) do not contradict the "remarkably conservative" nature of such a complex (Klein & Edgar, 2002, p. 107; see also Klein, 2009, p. 380). Therefore, "Acheulean people seem to have been nearly as conservative as their Oldowan predecessors" (Klein, 2000, p. 23).

The Mousterian techno-complex appears about 300 ka ago. Its defining feature is that core carving is in general abandoned, and lithic industry becomes based on flakes detached from the core. Mousterian is mainly characterized by the highy complex Levallois reduction technique (see Dibble & Bar-Yosef, 1995; Wynn & Coolidge, 2010), by which flakes of predetermined size and shape are obtained through a careful preparation of the core. Although Mousterian shows more variation than previous industries, it "is remarkably uniform through time and space" (Klein, 2009, p. 500), in such a way that "the range of tools and knapping techniques remained virtually unchanged for approximately 200 millennia until the appearance of Chatelperronian" (Coolidge & Wynn, 2004, p. 61; see also Mithen, 2007, p. 323). That amounts to saying that Neanderthals lacked "conscious experimentation and creativity" (Wynn & Coolidge, 2004, p. 476).

This picture dramatically changes with AMH. Although they first use Mousterian techniques, as evidenced in the Levantine Corridor, they develop an unprecedented technology in the Middle Stone Age, as testified by South African sites like Klasies River Mouth (elongated blades of the Howieson's Poort industry) or Blombos Cave (microliths), and new raw materials are used to produce tools. As opposed to the static nature of prior complexes, with AMH an impressive succession of industries is observed (see Klein, 2009): for example, in the Nile Valley six clearly differentiated lithic industries follow one another between 40-17 ka, and a similar picture holds for Europe between 40-11 ka. The rhythm of technological invention is unprecedented.

It is not difficult to suppose that stasis and lack of stasis can be respectively correlated with the absence and presence of FL, given the great cognitive power language endows one with.

externalization of thought, and, accordingly, they clearly point to the full emergence of FL. These changes, associated to what has been named the 'great leap forward' (Diamond, 1992), reveal an unprecedented cognitive flexibility and a powerful creativity (see Box 5). This creativity seems unlikely in the absence of a system like language: language provides a great cognitive power, and makes it possible to transcend immediate reality and build every kind of mental model (Dennett, 1995, 1996), in such a way that we can imagine many events which have not taken place. Accordingly, the emergence of FL is the obvious candidate for explaining those behavioral changes: "It is commonly assumed that whatever the human intellectual capacity is, the faculty of language is essential to it" (Chomsky, 2005, p. 3).

What about earlier hominids? Clearly, the situation was very different, even for Neanderthals, who coexisted with AMH in Europe for some thousands of years (see the reviews by Balari *et al.*, 2008, 2013). The vast majority of proxies of modern behavior are absent in Neanderthals. Therefore, modern behavior is linked to AMH, and emerged within the African Middle Stone Age, but it is absent from many and well known Mousterian sites from the European Middle Palaeolithic, in spite of claims to the contrary (Frayer *et al.*, 2010; see the debate between Benítez-Burraco & Longa, 2012b and Frayer *et al.*, 2012). All of this suggests a worldview and a cognitive make-up lacking FL.

An alleged exception to the Mousterian stasis is the existence of some late Neanderthal cultures, like Chatelperronian (south of France and north of Spain) and its equivalents in other European areas (Uluzzian in Italy, Szeletian and Bohunician in Central Europe, etc.). According to d'Errico (2003), d'Errico *et al.* (1998) or Zilhão *et al.* (2006), those cultures reveal that Neanderthals showed the same behavioral modernity found within AMH: "late Neandertals were already developing their own transition to the Upper Palaeolithic" (d'Errico, 2003, p. 196) before the arrival of AMH. Those cultures have elements that were unknown in the Mousterian complex (blade technology, perforated or grooved ornaments, etc.), and therefore Neanderthals would be cognitively, behaviorally and linguistically modern beings. However, many scholars reject that interpretation (see Balari *et al.*, 2008 for a review): it would certainly be odd that Neanderthals, characterized by a highly static culture for more than 200 ka, suddenly became innovative at the point when AMH, among which those objects are well attested, were expanding across Europe. That 'impossible coincidence' (Mellars, 2005) makes that thesis improbable. The most likely option is that Neanderthals imitated (or emulated, according to Coolidge & Wynn, 2004) those objects from AMH. In addition, doubts have been recently raised about the association between Neanderthals and both Chatelperronian (Higham *et al.*, 2010; see also Mellars, 2010; Bar-Yosef & Bordes, 2010) and Uluzzian (Benazzi *et al.*, 2011; Benazzi, 2012).

In light of those facts, the most parsimonious hypothesis is that FL was only possessed by AMH, and, accordingly, that FL did not evolve gradually (see Boeckx, 2011). If FL had evolved gradually, with many intermediate stages of growing complexity, as argued for by Pinker & Bloom (1990) (but see Longa, 2006), the archaeological record would be expected to show a gradual emergence of modern behavior and symbolism in different species. However, there are no hints of that before AMH. The converging evidence suggests (1) that FL is a recent evolutionary outcome, uniquely linked to AMH, and (2) that it arose in the African Middle Stone Age.

To conclude this section, according to mainstream Generative Grammar, FL is a uniquely human capacity that consists of a "linguistically specific computational system" (Lust, 2006, p. 265). The following sections pursue a twofold objective: on the one hand, they will raise doubts about the supposed specificity of FL, by arguing that the notion of FLN (the specifically linguistic and human 'bastion' of language) is empty, although language can still be considered a species-specific feature. On the other, they provide the reader with a novel way of reading and interpreting the archaeological record that strongly departs from the usual ones. I will first approach this issue, from which the discussion on the specificity of FL will be brought to the fore.

The computational approach on prehistoric remains

The types of evidence traditionally considered by Paleoanthropology for inferring language origins and evolution have mainly relied on the two adjacent systems with FL: on the one hand, analysis of fossil evidence (vocal tract, and the like, thus linked to the A-P system), and, on the other, analysis of symbolic, technological, social, etc., evidence (linked to the C-I system). Therefore, it is safe to say that archaeological remains have usually been regarded from the perspective of the behavior they could be associated with (symbolic, technological, of speech, etc.). However, it is also possible to consider them from the perspective of the mental computational processes and capabilities required for their production, such a view perfectly agreeing with the fact that FL is a computational system, not a behavior.

Box 6. Knots and language

Piattelli-Palmarini & Uriagereka (2005) and Camps & Uriagereka (2006) propose an intriguing hypothesis that could help determine the computational capabilities possessed by the creators of prehistoric objects (see also Balari *et al.*, 2011): to analyze evidence for knotting in the archaeological record. Knots are complex operations computationally, because they show the property of context-sensitivity (see main text) and, consequently, a language-like computational complexity. Of course, the particular knotting techniques are cultural practices, but underlying those traditions there exists a computational capacity; in addition, it should be noted that the relationship between the inventories of existing knots and the underlying computational capacity is basically the same as the one that exists between specific languages as historical instances of language and FL.

According to those papers, a knot requires applying an operation on previously computed operations, which must be kept in working memory until the overlapping needed for knotting is made (Camps & Uriagereka, 2006, pp. 46-51). Therefore, a sophisticated working memory is required for the derivational record to be kept. This procedure may be represented with the structure [A_1 [B [C D_1]]], where a long-distance relation results [A_1…D_1]. The capacity of processing this kind of relation is a formal property pervading language (see main text). Abstracting away from the 'semantics' of the involved symbols, that structure also characterizes a sentence like

[$What_1$ did John say [that Mary thinks [that Peter knows $\_\_\__1$?]]]

In it, 'what', generated in the object position of the verb 'know', has moved to the first position, thus creating a long-distance relation formally similar to that involved in knots. Therefore, "evidence for knot-tying is computationally equivalent to modern linguistic evidence" (Camps & Uriagereka, 2006, p. 46).

Although knots are not attested to until about 27 ka ago (weaving), they can be inferred long before (Piattelli-Palmarini & Uriagereka, 2005, p. 41; Camps & Uriagereka, 2006, p. 35) in domains like perforated ornaments (beads, teeth, shells) and small projectile technology (arrow heads, arches, harpoons). The oldest evidence for objects like those is about 90-75 ka (but see Vanhaeren *et al.*, 2006 for even older ornaments), and that suggests that AMH "had achieved modern language by that time, with its full-blown context-sensitive potential" (Piattelli-Palmarini & Uriagereka, 2005, p. 42). However, no evidence for knots is found among Neanderthals: Mousterian projectile technology implies hafting, not knotting, and Neanderthals did not make personal ornaments until late stages, when AMH had reached Europe. The absence of knots suggests that Neanderthal computational capabilities were not high enough for complex language. Recently, Zilhão *et al.* (2009) report the discovery of Neanderthal perforated shells of more than 50 ka found at Aviones, Spain. However, as pointed out by Lorenzo (2012), the fact that those perforations were due to natural causes does not invite one to associate those ornaments with high computational capabilities.

This approach, which derives from Chomskyan formal linguistics (although, paradoxically, it has scarcely been considered by this framework) and assumes a computational view of mind (Fodor, 1975; Gallistel & King, 2009), seeks to develop a purely formal analysis of archaeological objects that may reveal a computational complexity in the minds of their creators of the same type as that involved in language. Firstly proposed by Piattelli-Palmarini & Uriagereka (2005) and Camps & Uriagereka (2006) (see Box 6), such an approach could become a useful tool for Paleoanthropology, given the indefinite nature of many types of evidence used for inferring language evolution (see an in-depth discussion in Balari *et al.*, 2013).

Because "A computable process is simply one that can be carried out by an algorithm" (Savitch *et al.*, 1987, p. xi), from the computational approach the key is to find out what type of algorithm (and complexity associated with it) may computationally describe a rube-based procedure. The so-called Chomsky hierarchy is a useful tool for this approach to be developed (see Chomsky, 1956, 1959; Levelt, 2008; Fitch & Friederici, 2012; Balari & Lorenzo, 2009, and especially Balari & Lorenzo, 2013, chs. 1 and 5). The hierarchy establishes several types of grammars arranged in an increasing scale of computational complexity, and formal languages generated by such grammars (strings of symbols generated under certain admissibility conditions).

At the same time, it relates those grammars with types of automata (abstract computational machines studied by automata theory) that can accept those formal languages. According to Levelt (2008, p. 2), grammars and automata may be mere notational variants.

That means that the hierarchy (1) establishes upper and lower limits on computational capabilities, (2) characterizes several computational regimes or Types between both limits, and (3) identifies their abstract properties. The Types defined by the hierarchy are as follows, from the less powerful computational Type to the most powerful one:

- Type 3: Regular systems. Computational power equivalent to a finite-state automaton
- Type 2: Context-free systems. Computational power equivalent to a pushdown automaton
- Type 1: Context-sensitive system. Computational power equivalent to a linear-bounded automaton

Two clarifications are in order. Firstly, the Chomsky hierarchy establishes a fourth regime, Type 0 (unrestricted systems), its computational power being equivalent to a Turing machine. However, I will ignore it, for it has infinite space (memory) and time resources; no equivalent of that Type can be found in natural computation systems. Secondly, and importantly, the relationship between the Types is inclusive: Type 2 contains Type 3, and Type 1 contains both Type 2 and Type 3.

I will briefly characterize the main features associated with the three Types. Type 3 systems can process strings whose structure relies on strictly sequential steps, independently from their length. Thus, it can generate formal languages like 'a*' (iterate 'a' *n* times), '$[ab]_n$' (iterate [ab] *n* times), or '$a_n b_m$' (iterate 'a' *n* times, and 'b' *m* times, $n \neq m$). That amounts to saying that Type 3 can perfectly deal with linearly ordered strings: from a finite state *n* to another finite state *n*+1.

Although Type 3 may perform quite complex computations, it has a major shortcoming: its associated automaton (finite-state automaton) lacks memory, where 'computational memory' simply means the capacity for storing instructions that will be used in later stages of the computation (Camps & Uriagereka, 2006; Balari *et al.*, 2011). Therefore, it cannot store an element in order to be used in later stages of the computation. This explains why Type 3 cannot generate a language like '$a_n b_n$': for this task to be done, it would be necessary to keep in memory the number of 'a's in order to match them with the same number of 'b's. To accomplish this, a more powerful regime is required, Type 2 (context-free grammar), because as opposed to Type 3, Type 2 is endowed with memory. Its associated automaton (pushdown automaton) has an external storage mechanism, a memory stack, in such a way that it can keep in memory the number of 'a's until the last 'b' of the series is generated, thus being able to match the length of both substrings.

However, Type 2 has a significant constraint: the amount of memory of its associated automaton is limited. That means that it cannot deal with a formal language like '$a_n b_n c_n$'; for this language to be processed, a more powerful memory is needed, for it is necessary to keep in memory the number of 'a's and 'b's in order to match the number of 'c's with the number of 'a's and 'b's. This task can only be successfully done by a Type 1 computational regime (context-sensitive grammar). Its associated automaton (linear-bounded automaton) is endowed with a more powerful memory, a stacks-within-stacks structure that permits carrying out more powerful computations.

A key aspect of the three Types (and their associated automata) is whether they can deal with long-distance relationships or dependencies (henceforth, LDDs). As introduced in Box 6, an LDD is a relationship established between two non-adjacent elements [A_1 […] B_1], where one of them must be stored until it can be matched by the other within a given space of search, in such a way that the LDD is resolved. This means that, for LDDs to be processed, the system must have memory. This said, how well do the three types deal with LDDs?

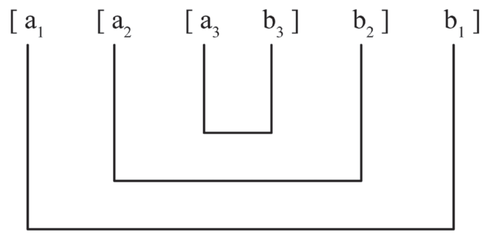

Fig. 1 - Nested dependencies.

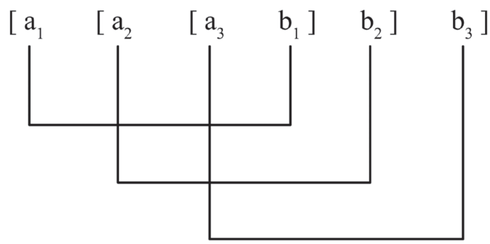

Fig. 2 - Cross-serial dependencies.

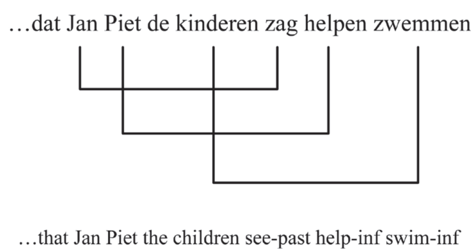

Fig. 3 - Cross-serial dependencies in Dutch. Based on Bresnan et al. (1987, p. 288).

As regards Type 3, the answer becomes obvious: because a finite-state automaton lacks memory, Type 3 is unable to process LDDs. Type 2 behaves differently: its corresponding automaton, pushdown automaton, has a memory stack. Therefore, Type 2 is able to cope with LDDs. However, because the memory stack is not powerful, it can only deal with one LDD at each stage: the last item stored in the stack is the first one to be recalled and come out. For example, if the language '$a_n b_n$' is projected into a context-free grammar, the resulting structure is shown in Figure 1.

This structure shows nested dependencies (an important aspect of natural language), based on embedding relationships: [a_3b_3] is embedded within [a_2b_2], and [a_2b_2] is embedded within [a_1b_1], thus giving rise to two LDDs (a_2b_2, a_1b_1). However, the constraints on memory determine that in Type 2 only one LDD can be stored and resolved at each stage: the stack stores the three 'a's and pops them out as we add 'b's to the string: when [a_2b_2] is processed and resolved, [a_1b_1] is processed and resolved in turn. This means that a pushdown automaton is unable to process the structure of Figure 2.

This structure has cross-serial LDDs that need to be stored until they are resolved. A simple memory stack cannot accomplish the task, which simultaneously requires the establishing of an LDD between two items and the holding in memory of another item between the former two for subsequent computations. Cross-serial LDDs need to be processed by an automaton with enhanced memory (linear-bounded automaton), corresponding to Type 1 (context-sensitive grammar), because the memory of this automaton has a stack-within-a-stack structure. Given that the last item stored in the stack needs not to be the first item to be recalled, Type 1 can simultaneously process more than one LDD.

LDDs are relevant because they offer a measure of the computational complexity of natural language; in fact, LDDs pervade language, by adopting many faces:

- Agreement: The professor_1 who wrote the paper needs_1 an assistant
- Binding: Peter_1 wonders which portrait of himself_1 was stolen
- Control: She_1 never promised PRO_1 to marry John
- Displacement: Which students_1 did the dean say the police arrested t_1 yesterday?

That said, a crucial question comes to the fore: what Type of the Chomsky hierarchy characterizes FL? The answer is clear, FL is a Type 1 computational regime (context-sensitive), because Type 1 is the only one able to process cross-serial LDDs. Papers like Bresnan *et al.* (1987) showed that Dutch has these kinds of dependencies between verbs and their arguments, as Figure 3 makes it clear.

Because "there is no context-free grammar [Type 2; VML] that can assign the correct structural description to Dutch cross-serial dependency constructions" (Bresnan *et al.*, 1987, p. 314), Type 1 becomes necessary for cross-serial LDDs to be processed. More specifically, FL is a mildly context-sensitive system (Joshi, 1985), because while linguistic structures with cross-serial LDDs can only be processed with Type 1, other structures, like those showing nested dependencies, can be processed with Type 2. This means that FL does not presuppose the overall power presupposed by Type 1 (let us remember that the hierarchy is inclusive, in such a way that Type 1 includes Type 2).

We should note that, far from being an idiosyncratic feature of Dutch, LDDs pervade any language. English examples illustrate:

- If$_1$ John explains the Chomsky hierarchy$_2$, then$_1$ you will understand it$_2$
- The scholar$_{1,2}$ who studies$_2$ the Chomsky hierarchy$_3$ has$_1$ written many papers about it$_3$

Therefore, linguistic computations presuppose powerful memory resources, those corresponding to a Type 1 computational regime.

The exposition shows, as emphasized by Balari & Lorenzo (2009, 2013) or Balari *et al.* (2011, 2012) that the several Types of computational complexity defined by the Chomsky hierarchy are not to do with the computational system itself, but with the amount of memory the computational system is endowed with: "the progression up the scale of complexity is a function of the changes introduced in the memory system, with no other modification of any fundamental property of the computational system being necessary" (Balari & Lorenzo, 2013, p. 99). It is worth noting that from a different theoretical background Petersson *et al.* (2012, p. 84) fully agree with that view: "From the point of view of computability theory, the Chomsky hierarchy is in essence a memory hierarchy, which specifies the necessary (minimal) resources required for a given level of computational complexity". Therefore, the more memory the system has at its disposal, the more computational power it has: a computational system with memory (Types 2 or 1) is more powerful than a system without memory (Type 3), and a Type 1 system, with a sophisticated memory, is more powerful than Type 2, endowed with a more basic one.

The Chomsky hierarchy may be a very useful tool for investigating computational complexity (see Box 7),, because any computationally tractable problem can be related to one of the types the hierarchy is composed of. This means that this perspective may shed light on whether or not a hominid species had the computational requirements for complex language. Although this is not possible in a direct way, an indirect strategy (any appraisal of language evolution relies on indirect types of evidence) for knowing that is analyzing prehistoric remains in order to determine what Type of the hierarchy is presupposed by the computational capabilities required for producing those remains (of course, this does not mean assuming the existence of an automaton in the head; the view just characterizes abstract models of computational capabilities). For example, if the formal complexity of computations needed to perform a Levallois point, a geometric engraving, a parietal representation, etc., is equivalent to the computational power of a finite-state automaton, the computational system of the creature would be Type 3, thus being unable to deal with complex language; if such a formal complexity is equivalent to a pushdown automaton, the computational system would be Type 2, able to process some linguistic structures (nested dependencies), but unable to process other structures (cross-serial dependencies); finally, if the complexity of computations is shown to be equivalent to a linear-bounded automaton, the computational system would be Type 1, the creature consequently being computationally ready for complex language.

Although prehistoric remains do not have a linguistic nature, language can be indirectly inferred in their executors. As Balari *et al.* (2011, p. 10) argue, this enterprise is realistic because FL interfaces with other cognitive systems, and through them, with general cognition. Let us imagine that

Box 7. On the usefulness of the computational approach for Paleoanthropology

One of the key notions in Paleoanthropology is that of complexity, for any approach to evolution of cognition is based on it, whether explicitly or implicitly: for example, complexity of lithic tools (is a Levallois point more complex than a biface?), complexity of representations (are geometric representations more complex cognitively than figurative ones, as argued for by Bednarik (2003, p. 101), or the other way round?), etc.

Although within a single domain (for instance, technology) it is possible to determine the complexity of given procedures, Paleoanthropology lacks a common complexity measure for comparing different tasks from one another (i.e. tasks which belong to different domains), and for developing reliable correlations among them. Precisely, the usefulness of the Chomsky hierarchy is that it makes it possible to computationally describe any rule-based task, therefore providing us with a unique scale for assessing the computational complexity underlying any behavior. As Fitch & Friederici (2012, p. 1936) put it, the hierarchy offers "an explicit, formal axis along which any particular algorithm can be placed, which thus provides one useful dimension along which to characterize the rule-governed capacities of a machine, or a human or animal subject" (see also O'Donnell *et al.*, 2005).

the analysis of some prehistoric remains reveals a Type 1 computational system (context-sensitive); if so, three possibilities arise: (1) context-sensitivity is linked to a mental capacity unrelated to FL; (2) it depends on some interface with FL (it is subsidiary of language); and (3) it derives from an unspecific computational system underlying any cognitive or motor activity the creature is engaged in. Obviously, option (1) is unrealistic, for it would mean the existence of different properties of context-sensitivity unrelated to one another, despite the fact that their computational properties are the same (options 2 and 3 will be discussed below).

A computational analysis of prehistoric geometric engravings

Prehistoric lines 'speak'

This section illustrates the computational approach with an innovative analysis of some prehistoric geometric engravings. The analysis will extend the scope of such an approach beyond knots. I will concentrate on two types of designs: geometric designs from the Eurasian Lower and Middle Palaeolithic (*Homo neanderthalensis* and perhaps *Homo heidelbergensis*), and from the African Middle Stone Age (AMH). The analysis will seek purely formal features of the pieces that may reveal the computational regime possessed by the executors of the engravings. Therefore, I will aim at showing that the arrangement of the lines permits us to infer whether or not a given species was computationally ready for FL. Although the analysis is restricted to a few pieces, the comparison of both types of designs will nevertheless show systematic patterns.

Geometric engravings began proliferating with AMH, but they are not unknown in earlier hominids.

Figure 4 shows two of the geometric engravings found at the sites of Bilzingsleben (upper) and Oldisleben (lower) (Germany). Although both sites are close to one another (10 kms.), the temporal difference between the two pieces is huge, about 250 ka: the Bilzingsleben engraving dates from 350 ka (Bednarik, 2003, p. 99). This suggests that it could be made by Heidelbergensis, according to the usual dating of appearance of Neanderthals, about 300 ka (Harvati, 2010, p. 367). However, the Oldisleben piece dates from 80 ka; therefore, it was engraved by Neanderthals. In spite of that temporal difference, both pieces (and the remaining pieces from the two sites) share a nearly identical design, based on parallel lines, with two series of lines that show different orientation.

The same arrangement applies for other pre-AMH geometric engravings, which also rely on parallel lines. They are shown in Figure 5.

The upper part of Figure 5 shows an engraved bone fragment from La Ferrassie (France), a Neanderthal piece dating from 75-65 ka (Langley *et al.*, 2008, p. 297). Its design relies on series of parallel lines with different orientation. Again, such a basic design is appreciated in the piece shown in the lower part of Figure 5, a shale with Neanderthal engravings found at the Temnata site (Bulgaria), of about 50 ka (Crémades *et al.*, 1995), with the difference that its parallel lines exhibit only one orientation.

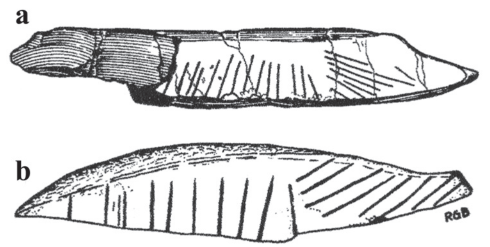

Fig. 4 - Upper part: engraving from Bilzingsleben. Lower part: engraving from Oldisleben. From Bednarik (2003, p. 99), reproduced with permission of the author, copyright owner.

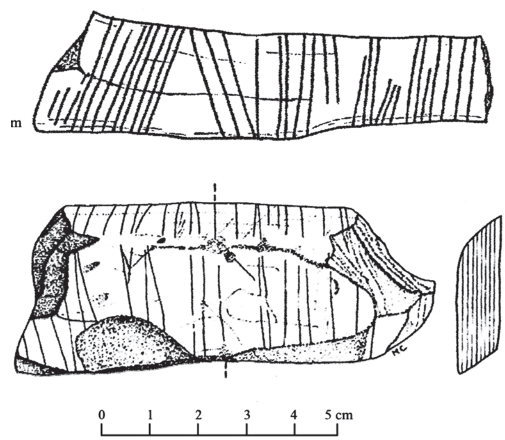

Fig. 5 - Upper part: bone fragment from La Ferrassie. From Bednarik (2003, p. 98), reproduced with permission of the author, copyright owner. Lower part: shale from Temnata. From Crémades et al. (1995, p. 205), reproduced with permission of Paléo.

It is worth noting that some objects traditionally attributed to Neanderthals (or Heidelbergensis) have been shown to be due to natural causes. As d'Errico *et al.* (2003, p. 18) put it, "In the last few years, we have examined materials considered by some to exhibit the attributes of behavioral modernity, but many of these objects must be rejected because of modification by natural processes". This applies to geometric engravings, for several designs attributed to species prior to AMH, and, crucially, based on a more complex design than parallel lines (criss-cross lines), have been shown to be (1) natural pieces, or (2) non-intentional designs (see d'Errico, 2003; d'Errico & Villa, 1997; Soressi & d'Errico, 2007, and the survey by d'Errico *et al.*, 2009, pp. 28-29).

That is the case, for instance, of a well known piece, a rib with alleged geometric engravings from the Mousterian site of Pech-de-l'Aze (France), dating from more than 300 ka; d'Errico & Villa (1997) demonstrated that the engravings were vascular grooves. Both d'Errico *et al.* (2003, p. 18) and d'Errico *et al.* (2009, p. 28) argue for the natural character of other alleged pre-AMH designs, like those of Stranska Skala (Czech Republic), Morín Cave (Spain) or Bois Roche (France), that "have been misinterpreted" (d'Errico *et al.*, 2003, p. 18). As regards several bone objects from Molodova IV site (Ukraine), Nowell & d'Errico (2007) found that those objects with supposed Neanderthal engravings were not intentional, a point already made by d'Errico *et al.* (2003, pp. 18-19). The same situation holds for alleged incised pebbles, some of them with crossed lines, from the Neanderthal sites of Chez-Pourre-chez-Comte and Champlost (France): according to Lhomme & Normand (1993), the incised lines were not intentional: the pebbles were the basis over which skin was cut with a silex tool, this tool being responsible for the incisions.

In addition, some intentional pieces based on a more complex design than parallel lines have sometimes been attributed to Neanderthals, but according to many scholars, those pieces were engraved by AMH. For example, Marshack (1996) contends that the piece found at Qneitra

(Golan Heights), of about 54 ka, could have been engraved by Neanderthals or by AMH, but Marshack (1997) assumes that the AMH engraved the piece before entering Europe.

All of that leads to two interesting generalizations:

1) On the one hand, pre-AMH unequivocally intentional geometric engravings are based on parallel lines, not on crossed lines.
2) On the other, alleged more complex pre-AMH geometric engravings, based on criss-cross patterns, (1) are not intentional, or (2) derive from natural causes.

Those generalizations are remarkable from the computational perspective, because the complexity of computations needed to perform engravings based on parallel lines does not require a high computational regime in the Chomsky hierarchy. Actually, their complexity is equivalent to the computational power of a finite-state automaton, an automaton lacking memory. Let us note that the parallel lines of the Temnata piece are formally similar to formal languages like 'a*', and the lines of pieces like those from Bilzingsleben, Oldisleben and La Ferrassie are similar to formal languages like '$a_n b_m$'; in the first case, a line is engraved *n* times (parallel lines with one orientation); in the second, a line with an orientation x is engraved *n* times, and then another line with an orientation z is engraved *m* times. Because the number of the first substring of lines is different from the number of the second substring, it is not necessary to keep in memory the number of 'a's in order to match the number of 'b's. This coincides with the assessment from more traditional premises of geometric designs from the Lower and Middle Palaeolithic: "none show complex structured designs" (Henshilwood *et al.*, 2009, p. 27).

The conclusion is that those engravings do not permit us to infer computational capabilities beyond Type 3. This Type proceeds through purely sequential steps, without any kind of external storage; the only step within the series that can be accessed is the immediate previous step, for which no computational memory is required (the same applies to the zig-zag pattern from Bacho Kiro). To conclude, the computational system of species like Neanderthals or Heidelbergensis was much less powerful than the computational complexity required for FL. Importantly, this conclusion agrees with the absence of knots in the Neanderthal record.

Anyway, to say that the Neanderthal computational system was not powerful enough for supporting FL does not mean that Neanderthals lacked a communicative system. Undoubtedly, they had one, and it had to be efficient (Wynn & Coolidge, 2012, ch. 6). What that claim means is that Neanderthal's communicative system was not a complex language, as it lacked hierarchical structure, nested and cross-serial dependencies, etc. It could be something like a protolanguage (Mellars, 1996; see Johansson, 2013 for discussion), based on a linear organization, this proposal fitting in well with a regular system (Type 3), restricted to purely sequential operations.

A very different picture emerges when AMH geometric engravings are computationally analyzed. In the last few years, important pieces have been discovered which, by the way, have helped validate McBrearty & Brooks' (2000) criticism of the 'human revolution' traditional model, which assumed that modern behavior suddenly appeared in Europe at 45-40 ka ago. According to McBrearty & Brooks (2000, p. 453), "many of the components of the 'human revolution' claimed to appear at 40-50 ka are found in the African Middle Stone Age tens of thousands of years earlier". Precisely, some of the main recent discoveries have been geometric engravings. As opposed to pre-AMH engravings, AMH engravings may be related to a higher computational regime, which, crucially, presupposes LDDs and memory to deal with them.

Figure 6 shows an engraved ochre piece found at the Klein Kliphuis site (South Africa), dated to between 80-50 ka. Interestingly, MacKay & Welz (2008) could determine the exact ordering of the engravings: "the vertical lines generally appear to have been laid down first, followed by the central horizontal, and finally the upper and lower lines" (MacKay & Welz, 2008, p. 1525). Such an ordering permits us to infer

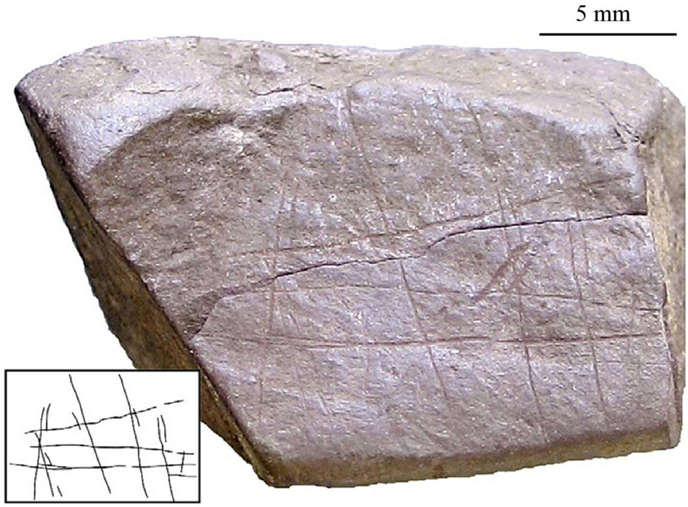

Fig. 6 - Engraved ochre from Klein Kliphuis. From Mackay & Welz (2008, p. 1525), reproduced with permission of Elsevier.

the computational requirements involved in the engraving of the piece: after the engraving of the vertical lines, these lines need to be kept in working memory, for they will become the key reference for engraving the central horizontal line. At this point, vertical lines are no longer required; therefore, memory frees them and stores the central horizontal line in order to engrave the upper horizontal line. In turn, memory keeps both horizontal lines for engraving the lower horizontal line. The process can be formalized as follows:

$$[[vl_1\ vl_2\ vl_3]\ [[hl_{centr}\ hl_{upp}]\ hl_{low}]]\ \text{(vl=vertical line; } hl_{centr}\text{=horizontal central line, etc.)}$$

We can note the existence of LDDs, which presuppose memory, LDDs being intractable by Type 3. More specifically, this piece shows the LDDs which are characteristic of nested dependencies: when the second LDD is resolved (([Ø hl_{centr} hl_{upp} hl_{low}]), the first one ([Ø vl_1 vl_2 vl_3 hl_{centr}]) has been previously resolved. Therefore, only one LDD is processed and resolved at each stage. This means that this structure may be formally related to a Type 2 computational regime, characterized by a memory stack which may retain elements (thus giving rise to LDDs), but restricted to the processing of only one LDD at each stage. These characteristics unequivocally show that the computational power involved in the engraving of the Klein Kliphuis piece clearly surpasses that of pre-AMH designs.

At this point, a crucial aspect for the formal argument developed in the paper needs to be explicitly stated: to (learn to) execute a motor task (like tying a knot or engraving a piece) is not evidence enough in itself to contend that a high computational regime in the Chomsky hierarchy is involved. An example illustrates: some apes have been taught to tie simple knots, with a limited degree of success (Herzfeld & Lestel, 2005). However, this ability implies a mechanical motor learning lacking the property of creativity (i.e. diversity of structures) by which humans have invented multiple new knots over millennia. The point is simple: to learn to tie a knot as a motor task presupposes no more than a Type 3 regime (regular grammar), based on purely sequential steps. This means that any process within a rule-governed procedure seemingly surpassing Type 3 can be reduced to Type 3 if the procedure does not generalize. Creativity (i.e. diversity of structures) is the hallmark of Types 2 and 1, this property (also crucial in language by means of discrete infinity) being out of reach of Type 3.

The same argument is applicable to geometric engravings: in order to attribute a computational regime beyond Type 3 to AMH, a single piece like that of Klein Kliphuis is not enough. To surpass Type 3, engravings should show the property of creativity, not accessible to Type 3. That requirement is borne out: as opposed to the absence of diversity of structures in pre-AMH engravings, AMH engravings reveal an open-ended creativity. In recent years, engravings with different designs, and made in disparate times and places have been discovered which show the differences between the pre-AMH and AMH computational system.

Some of these designs are not based on criss-cross lines, but on parallel ones; however, interestingly, the latter are computationally more complex than those produced by pre-AMH, thus pointing to Type 2. This is the case of 270 fragments of ostrich engraved eggshells found at the Diepkloof site (South Africa), dating from 65-55 ka (Texier *et al.*, 2010). Some of the pieces were joined into larger fragments, thus revealing at least four types of different designs. They are shown in Figure 7 (upper part).

Let us consider the D or E designs (lower part of Figure 7), made up of two vertical series of parallel lines. If these engravings were restricted to just one string of parallel lines (a_1, a_2, a_3, etc.) instead of two, Type 3 would suffice to explain them: in that case, the lines could be engraved sequentially. However, two strings of lines exist, where each lower line is linked to its corresponding upper line, and this means that those designs presuppose a more powerful computational regime, i.e. Type 2. The reason is that between each upper line and its corresponding lower line an LDD arises. From the engraving of, say, the 'a' series, the engraved lines need to be stored in memory, for each of them becomes the reference for engraving the corresponding lower line. However, only one LDD is processed at each stage: when one LDD is resolved (say, a_1 and b_1), the following LDD is processed and resolved in turn (a_2 and b_2), and so on. We thus have the canonical characteristics of Type 2: a memory stack, and LDDs, restricted to one at each stage.

As a last example, let us concentrate on the M1-6 ochre piece from Blombos (Henshilwood *et al.*, 2002), dating from 77 ka, and shown in Figure 8 (upper part). The researchers could discover the specific ordering of the engravings of this ochre piece (lower part), a key aspect for inferring the computational regime involved in the piece.

This design does not presuppose a Type 2 computational regime, but Type 1, because the piece shows the property of context-sensibility. The reason at work is that, as shown in Figure 9, the lines maintain a complex series of cross-serial LDDs, which can be said to be equivalent to the linguistic examples discussed earlier. As opposed to the other pieces discussed earlier, where LDDs were processed and resolved one at each stage, in the Blombos piece several LDDs must be processed simultaneously until they are resolved. Therefore, the memory capacity must be more powerful than the memory a pushdown automaton is endowed with. To put it equivalently, for engraving this design, the need exists to have access to several elements at the same time in the memory stack, given the presence of several cross-serial LDDs that cannot be resolved in an ordered and successive way. Hence the property of context-sensibility: the capacity of storing elements in memory does not comprise only the last part of the stack (let us remember, in Type 2 the last item stored in the stack is the first one to be recalled and come out), but just any part within the stack (in fact, with several parts simultaneously). This is what context-sensitivity in a technical sense means. To summarize, the Blombos piece presupposes a Type 1 computational regime, fully equivalent to the formal complexity of natural language.

The specific ordering of the engravings, as determined by Henshilwood *et al.* (2009) (see Figure 8, lower part), permits us to rule out other procedures computationally less complex for the piece to be engraved. The most obvious procedure would be to have engraved the piece from left to right (or vice versa) with zig-zag lines: first, a sequence like '>>>>>', and then, the opposite series '<<<<<'. This hypothetical ordering, though, would not presuppose Type 1: after the engraving of the sequence '>>>>>', this sequence

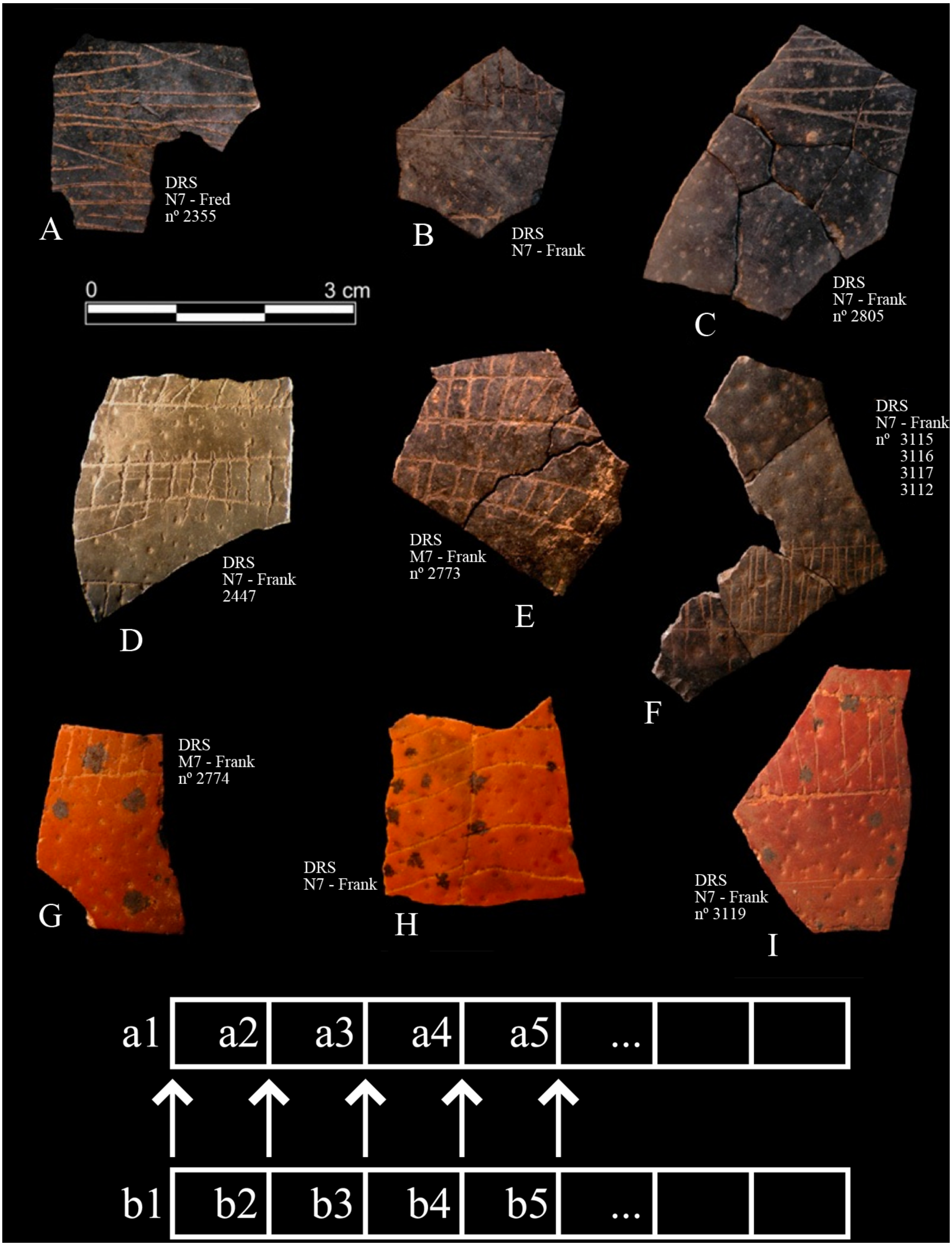

Fig. 7 - Upper part: engraved ostrich eggshells from Diepkloof. From Texier et al. (2010, p. 6181), reproduced with permission of PNAS. Lower part: structure of the D and E designs.

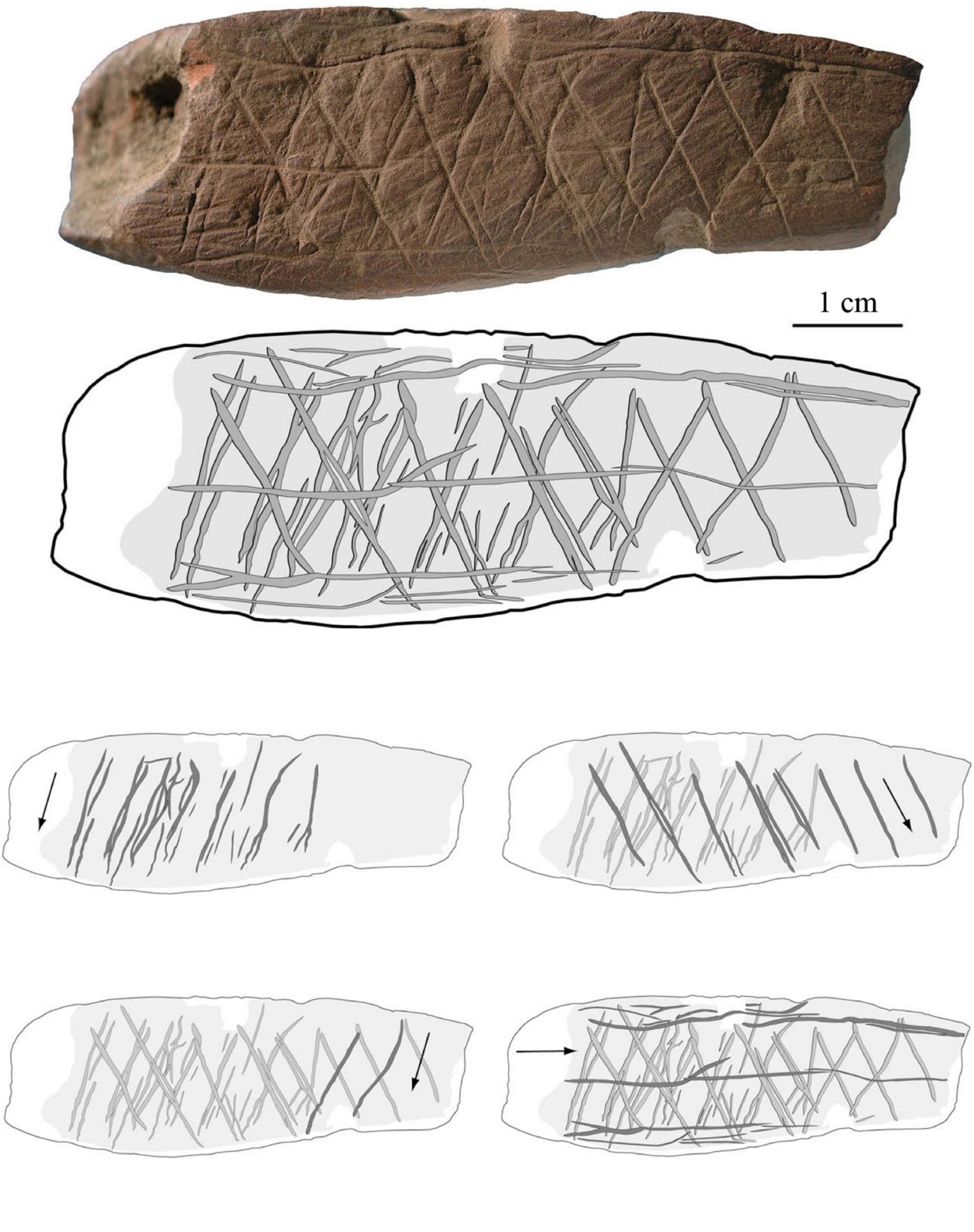

Fig. 8 - Upper part: M1-6 ochre piece from Blombos. Lower part: ordering of the engravings on the piece. From Henshilwood et al. (2009, p. 35), reproduced with permission of Elsevier.

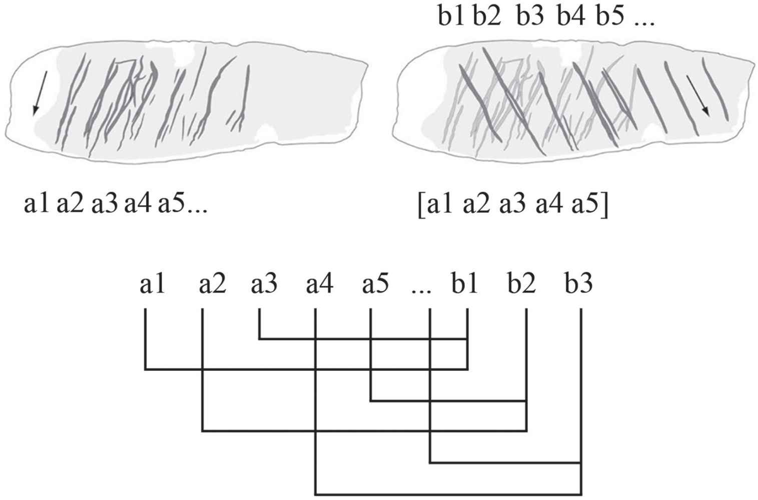

Fig. 9 - Cross-serial LDD on the M1-6 ochre piece from Blombos.

must be stored in memory, for it will become the reference for the opposite series: the point on which each new line of the second series begins relies on the initial and final points of each of the lines the first sequence is composed of. When each intersection is resolved, it can be erased from memory. In this case, the procedure would have involved a Type 2 computational regime, for the lines (and the corresponding LDDs) would be erased from computational memory in an ordered and successive way as they are linked to the lines of the opposite series. However, the piece was not engraved according to this procedure.

Moreover, the Blombos piece is older than the other AMH designs discussed above. Given the inclusive nature of the Chomsky hierarchy, the reasonable inference is that when that piece was engraved, AMH already had a Type 1 computational regime. This is independently confirmed by AMH's capacity to tie knots.

To sum up, the discussion developed in this section reveals a strong leap in the computational capabilities of AMH if compared to those of earlier hominids. That leap is supported by a great diversity of structures (creativity). This leads to the conclusion that the computational regime owned by AMH is the same regime involved in FL.

Do the computational and symbolic approaches conflate?

Although many types of evidence have been adduced for inferring language origins and evolution, "Symbolic manifestations are the most cited evidence for the emergence of language" (d'Errico *et al.*, 2009, p. 18). This derives from the wide consensus in Paleoanthropology concerning the impossibility of developing complex symbolic practices in the absence of a complex language; as McBrearty & Brooks (2000, p. 486) put it, "Abstract and symbolic behaviors imply language" (for similar statements, see d'Errico *et al.*, 2005, pp. 19-20; d'Errico *et al.*, 2009, pp. 18-19; Henshilwood *et al.*, 2002, p. 1279; Henshilwood & Dubreuil, 2009, pp. 45-46, and more generally, d'Errico & Henshilwood, 2011; Renfrew & Morley, 2009). The reason underlying this assumption is that symbolism must be supported by a powerful representational (and communicative) system like language, which makes it possible to transcend the here and now (see above), this capacity being at the heart of symbols. From that assumption it follows that the discovery of symbolic objects in the prehistoric record automatically implies the attribution of language to their creators. For this reason, much of the controversy about Neanderthal linguistic and cognitive capacities has concentrated on whether or not Neanderthals created symbolic objects: according to the symbolic approach, Neanderthal symbolic objects would mean that this species was endowed with complex language, i.e. FL. However, the computational approach makes a quite different prediction, which will be made explicit next.

In spite of the usual conflation contended by Paleoanthropology between symbolism and language, from the view of formal linguistics symbolic behavior is not valid evidence for the presence of FL (see Balari *et al.*, 2011), for linguistic symbols are not a subtype of symbols in general. Two reasons are at work: first, FL is not a behavior, but a natural system of computation; second, and especially, natural language semantics behaves differently from how cultural symbols become meaningful.

According to Eco (1975, ch. 2), cultures can only be understood as complex and opaque systems of significations. They are complex because the meaning of each specific component depends on the relationships it establishes with the remaining components of the system, and opaque (this feature being highly relevant) because we will hardly know the meaning of a specific symbol unless we know how it is used. However, this does not apply for natural language: once we know the meaning of given words (say, lion, angel, jumping, blue, attack) we automatically gain access to the meanings of their combinations (jumping lion, jumping angel, blue lion, blue angel, the blue lion which attacked the jumping angel, etc.). This is so even without previous familiarity with the situations in which these symbols could be appropriate. This means that natural language semantics is endowed with two properties that no cultural system of symbols exhibits: compositionality and productivity. The principle of compositionality implies that "the meaning of a piece of language is based solely on the meanings of its (linguistically relevant) parts, and the way they are put together" (Portner, 2005, p. 34). From this principle, creativity emerges, in such a way that an infinite array of expressions can be generated from the syntactic-semantic combination of a finite number of elements. The only known explanation for these two aspects is through the working of a computational system capable of dealing with hierarchical structures.

The contrast is thus clear: while the meanings of the elements making up a symbolic culture are opaque until we enter in contact with that culture, nothing of this applies to the meanings of linguistic complex expressions. We naturally grasp these meanings as we hear them, even with no prior exposition and in the absence of corresponding referents. Therefore, symbolic cultures and FL are different entities: the former are systems of complex and intricate culturally acquired behaviors, while FL is a natural component of the mind/brain (see Fodor, 1975). This suggests that the connection between both entities in humans could be a contingent fact (see below) on which it is not easy to place generalizations like those assumed by Paleoanthropology (the intimate link between language and symbolism). This is corroborated by the fact that nonhuman animals can acquire symbolic systems (Savage-Rumbaugh & Lewin, 1994), but no animal has been able to acquire or develop a combinatorial syntax.

The meaning of the said point is clear: usually the presence of language in Prehistory has been inferred from objects interpreted as symbolic. This has lead to controversies about whether or not given objects are symbolic, for it would mean automatically inferring the presence (or absence) of FL in the species that created them. If we consider geometric engravings to have been really symbolic pieces, the prediction of the symbolic approach is that pre-AMH geometric designs unequivocally indicate that Neanderthals were endowed with complex language. However, the prediction of the computational approach is quite different, from the disparate nature of linguistic symbols and symbols in general: those designs would not imply complex language, according to the computational processes (Type 3) those designs exhibit. Therefore, according to the computational approach, symbolism (as usually understood) and language are not necessarily linked to each other.

Discussion: how specific is Faculty of Language?

The exposition and illustration of the computational approach makes it possible to bring to the fore a relevant discussion for the evolutionary origins of language, which can be stated as follows: how specific is FL? To put it equivalently, is FL really specifically human and specifically linguistic? Hauser *et al.* (2002, p. 1578) and Fitch *et al.* (2005, p. 181) suggest that FLN could perhaps be empty; if so, none of its mechanisms would be uniquely human or unique to language: "only the way they are integrated is specific to human language" (Fitch *et al.*, 2005, p. 181). However, as explained above, that possibility has not received serious attention, for Chomsky and Generative Grammar have persistently contended that FL (i.e. FLN) is a uniquely human and a uniquely linguistic computational system.

From the computational approach this paper is concerned with, a different view arises. This view, suggested by Balari & Lorenzo (2009, 2013), contends that the biological machinery of language (not language itself), by which this feature has evolved is neither linguistic *per se* nor specifically human; with their own words, "the system in charge of recursion (not just recursion as an abstract property) subserves many other tasks (not just language) and is most probably a common feature of the brain of vertebrates (not just of humans)" (Balari & Lorenzo, 2013, p. 4). The computational system, or Central Computational System for Balari & Lorenzo (2013), would be an unspecific device, used not just by language but also by any other motor or cognitive task (or, at least, by many of them) an organism is engaged in (see also Balari *et al.*, 2012).

To fully appreciate this view, let us again take up the several computational regimes defined by the Chomsky hierarchy. In any of the three Types, the computational system is basically the same, the only difference among the Types being the amount of memory the system has at its disposal: no memory (Type 3), a basic memory (Type 2), or a sophisticated memory (Type 1). From a cognitive view, that means that many animals, perhaps all the vertebrates, share an unspecific computational system, their differences deriving from the memory associated with that common computational system: the more memory the system has at its disposal, the more computational power it is endowed with.

How plausible is the thesis of unspecificity of the computational system from a neuroanatomical and evolutionary perspective? Interestingly, it is quite plausible. Although the exact characterization of the neural substrate of the computational mechanism is being debated, currently it is clear that such a mechanism is based on the coordinated activity of both cortical and subcortical brain areas. The unspecific view finds support in Lieberman's (2000, 2006, 2007) Basal Ganglia Grammar Model. Lieberman's model (see Lieberman, 2006, p. 207 and ss.) characterizes a computational system composed of circuits that participate, among many other tasks, in the motor programming of speech, sentence comprehension, or walking, and derives from two main components:

1) On the one hand, an iterative sequencing device, or cognitive and motor pattern generator, which is located in subcortical areas (basal ganglia). Scholars like Graybiel (1997) had already noted the crucial role of the basal ganglia as pattern generators: "the basal ganglia may be critically involved in the control of cognitive pattern generators as well as motor pattern generators" (Graybiel, 1997, p. 459). According to Lieberman (2006, p. 208), the basal ganglia have an excitation/inhibition mechanism which functions as a switch, in such a way that "stored pattern generators are successively connected (activated) and disconnected (inhibited) to cortical targets to enable a rat to execute a grooming sequence […] or to allow me to write this sentence on the keyboard of my computer". This quote illustrates quite well that Lieberman considers this mechanism to be unspecific, and also not specifically human.
2) On the other hand, a working memory component, which is localized in cortical areas.

As the reader will note, it is not difficult to link both components to the main premises of the computational approach: the differences between the computational Types do not reside in the computational system *per se*, but on the amount of memory the system is endowed with. This also makes sense evolutionarily, for subcortical structures are much older than cortical areas, and "the evolution of the basal ganglia in amniotes has been very conservative" (Medina & Reiner, 1995, p. 235). Therefore, the picture emerges of a common computational system, which has been combined with a greater or lesser working memory space in different species, depending on the development of the cortex. We should note that the view can be sustained that disparate aspects like language and a motor-visual code like the one involved in performing geometric engravings, are activities resulting from the same computational system, despite the fact that the neural networks involved in those activities are not identical. In fact, Lieberman's prediction is that "The basal ganglia structures that perform the same basic operation, sequencing, in these different aspects of behavior [to move the fingers or to interpret sentences] support segregated neuronal populations that project to segregated neuronal populations in other subcortical structures and cortical areas" (Lieberman, 2000, p. 5).

An important implication is as follows: for the computational system to be operative, it needs to be connected to some external modules supplying their input and capable of receiving their output. Thus, the same unspecific computational system may become connected to different modules in different species. Among other aspects, this means that the connection of FL with the A-P and C-I systems may be a contingent, i.e. accidental fact. The contingent nature of the connection between FL and the C-I system was advanced above; on the other hand, the same contingent nature is even more clearly perceived in the interface between FL and the A-P system. Sign languages share the structural properties of oral languages, and this may show that the externalization of 'linguistic thought' does not privilege the vocal-auditory system; it is also possible to interface with a gestural-visual system. Let us also take into account that while the connection between the computational system and the A-P module is weak in nonhuman animals (they are only able to express to their conspecifics a little part of their C-I systems), it is much stronger in humans.

All of that leads us to characterize a second main parameter of variation in cognitive architecture. The first parameter, as already noted, is whether the computational system has memory, and if so, how much; the second parameter is concerned with the fact that the same computational system may become connected in different species with different modules (Balari *et al.*, 2012, p. 84; for a wide treatment, see Balari & Lorenzo, 2013). Therefore, there would be two axes of variation, with one of the axes corresponding to the working memory space the computational system has access to and the other axis corresponding to the number and kind of external modules the computational system interfaces with. The said architecture does not exclude, as sustained in Balari *et al.* (2011), the possibility of the existence of a computational system with powers similar to those involved in language, but interfaced with different mental modules; in this case, the system would implement completely different functions to those attributed to human language. To sum up, the differences are not to do with the computational system, but depend (1) on the amount of memory the system exhibits, and (2) on the modules it is connected to.

From this approach, as suggested by Balari *et al.* (2013) and Balari & Lorenzo (2013), the leap from the computational system to Type 1 (context-sensitive regime) may be linked to the development of the cortical structure which supports working memory, through an alteration in the developmental system of such a cortical structure. However, it should be remembered that the increase in working memory was not directly related to FL; it was unspecific. Much later, it became recruited for language, when the interface with C-I and A-P became contingently established.

Box 8. Evo-Devo: Placing development on the agenda

The Modern Synthesis (and the Neo-Darwinian framework which emerged from it) was a fundamental hallmark in biology, for it gave rise to modern biology. However, some of their effects were undesirable. One of them was gene-centrism, absolute primacy of the genes (for criticisms, see Blumberg, 2005; Moore, 2001; Moss, 2003; Oyama, 2000; Oyama *et al.*, 2001; from a linguistic perspective, see Longa & Lorenzo, 2008, 2012). Another undesirable outcome was to ignore development or, at least, leave it aside, thus favoring the dissociation between phylogeny and ontogeny (see Amundson, 2007; Robert, 2004). Two reasons underlie that dissociation: (1) since the Modern Synthesis, population genetics became the core discipline of Evolutionary Biology. Because population genetics studies the gradual change of genetic frequencies at the population level, the definition of evolution within Modern Synthesis as a process affecting populations, not individuals, led to a non-developmentalist theory (Moore, 2001, p. 167); (2) since the Modern Synthesis, development was considered to involve different explanations for different animals; therefore, "biologists had assumed that different types of animals were genetically constructed in completely different ways" (Carroll, 2005, p. 9).

Evo-Devo (see Hall & Olson, 2003; Hall, 1999; Carroll, 2005) has reversed the said disagreement between evolution and development, thus bridging the gap between both levels; as opposed to the traditional view sustained by Modern Synthesis (the evolutionary process derives from mutations operating on adults), Evo-Devo has revealed that evolution is accounted for by means of variations operating on developmental factors: "Phenotypic novelties are initiated in development and not by mutation" (Walsh, 2007, p. 193). Accordingly, "evolution is biased by development" (Raff, 2000, p. 78). Thus, it should not come as a surprise Gould's (2002, ch. 10) definition of Evo-Devo as the evolution of development.

I advanced above that the Modern Synthesis (and Neo-Darwinism) considered the development of different animals to involve quite different explanations: the more differences found between two given animals (humans and arthropods, elephants and mice, etc.), the more different their genes would be supposed to be. As Mayr (1963, p. 609) put it, "much that has been learned about gene physiology makes it evident that the search for homologous genes is quite futile except in very close relatives". Evo-Devo has shown that assumption to be mistaken: "despite their differences in appearance and physiology, all complex animals […] share a common 'tool kit' of master genes that govern the formation and patterning of their bodies and body parts" (Carroll, 2005, pp. 9-10). The differences among animal forms do not lie in the genes themselves, but on how, when and where the same genes work during development. Minor changes operating on regulatory mechanisms give rise to outcomes that are very different on the surface. To summarize, animal diversity has not to do with different genes, but with how the same genes are used differently.

This perspective is congenial to Evo-Devo (Evolutionary Developmental Biology; see Box 8). As opposed to Neo-Darwinian thought, the main premises of Evo-Devo may be summarized by the idea that evolution does not imply a constant process of diversification affecting adult phenotypes through mutations, but a process of diversification and substitution of the developmental models that lead to those phenotypes. Therefore, the phylogeny of the human brain may be explained, in the line of Balari *et al.* (2013) and especially Balari & Lorenzo (2013), as the result of a number of perturbations affecting its developmental pattern.

As discussed in Balari *et al.* (2013), the development of the human brain is characterized by a general model of late offset, which can be held responsible for its relatively large size with respect to other closely related species. For example, it is possible to appreciate a late offset of the symmetric cellular division phase of neuronal precursors, which produces an over-proliferation of such precursors; in addition, a late offset of cytogenesis is perceived, a phase starting with the onset of precursor production and ending with the phase where a maximum number of divisions obtains, and cells do not divide further but migrate to the forming cortical structure. The late offset of cytogenesis leads to an exponential growth of the cortical structure, while basal structures only grow linearly. These phenomena related to the developmental pattern of the human brain, together with other phenomena like the extension of fetal growth, the cortex myelinization (mainly in the frontal cortex), and the dendritic growth, strongly suggest that during the evolution of the

BOX 9. Other approaches to language evolution

Since 1990, a growing interest in language phylogeny has given rise to many different kinds of approaches. One of the main reasons for that diversity is the nature of language itself, a complex trait in which quite disparate levels of description (psychological, biological, social, representational, cultural, etc.) are simultaneously involved. As a result, linguistic theories significantly vary depending on: (1) The specific level/s highlighted in each case, and (2) the specific assumptions held about the corresponding level/s. Competing approaches on language evolution replicate this situation in the evolutionary domain. As Jackendoff (2010, p. 63) put it, "Your theory of language evolution depends on your theory of language".

Many of these approaches disagree with the Chomskyan view on language evolution. Contestation, particularly concerned with the issue of whether language is 'special', is even found within the generative approach itself. While Hauser *et al.* (2002) (see above) contend that FLN (recursion) is the only specifically human and specifically linguistic component, according to Pinker & Jackendoff (2005) many other facets of linguistic systems, like morphology, phonology, lexicon, etc., are language-specific as well; therefore, "there is considerably more of language that is special" (Pinker & Jackendoff, 2005, p. 204; see also Fitch *et al.*, 2005, and Jackendoff & Pinker, 2005).

Furthermore, as opposed to mainstream generative thinking, Pinker & Jackendoff (2005) argue that language is a complex adaptation for communication, and gradually evolved through natural selection (see also Pinker & Bloom, 1990). Other generative (Jackendoff, 2002; Newmeyer, 1991) and especially non-generative linguists (Bichakjian, 2002; Bickerton, 2009; Hurford, 2012) have also argued for a gradual and adaptive evolution of language. In a middle camp, Bickerton (1990) proposed that syntax emerged suddenly, although such an emergence was prompted by a gradual evolution of representations. As a particular implementation of gradualism, many scholars currently adopt the Baldwin effect (Baldwin, 1896, 1897; see Weber & Depew eds., 2003) as a guiding force in language evolution (Pinker & Bloom, 1990; Briscoe, 2003; Calvin & Bickerton, 2000; Kirby, 1999; for criticism, see Longa, 2006). The Baldwin effect is the hypothesis that learned behaviors may become inherited, thus affecting the direction and speed of evolutionary change.

Theories like functional or cognitive linguistics reject the innate bases of language sustained by Chomsky. The key assumption of functional linguistics is that "linguistic structure cannot be analyzed independently of the uses to which it is put" (Nuyts, 2007, p. 548). Therefore, communication (i.e. language use) has shaped language structure. The approach assumes that the human mind evolved by means of adaptations, but claims that "language and culture merely fall out, or emerge from, the biologically-evolved mind-brain, requiring no further specific adaptations" (Givón, 2002, p. xv). Within this approach, Bybee (1998) defends a continuist and gradualist position, while Givón (1998, 2002) assumes gradualism while rejecting continuism (see also Givón & Malle, 2002).

Cognitive linguistics basically shares this view. However, cognitivism contends that the core function of language is to express conceptualization, a function that arises from general cognitive resources (for a comparison between both frameworks, see Nuyts, 2007). Given the intimate link between categorization and meaning, for cognitivism "meaning must be the primary linguistic phenomenon" (Geeraerts & Cuyckens, 2007, p. 5), as opposed to functional linguistics' emphasis on linguistic structure. From a cognitivist point of view, Fauconnier & Turner (2002) consider that the key to explaining

human brain specific mutations affecting genes implicated in the regulation during development of processes like proliferation, division, migration and growth of neural cells could be crucial (see Balari *et al.*, 2013, and references therein), in addition to the reorganizational processes that accompanied this growth.

From this view, the relevant difference between cognition and behavior in Neanderthals and AMH could derive from processes like those pointed out above. This suggestion cannot be empirically demonstrated, but is congenial with the findings of recent studies that show differences in subtle anatomical details (Peña-Meilán *et al.*, 2011) and, especially, in the early developmental path of the organ in both species (Gunz *et al.*, 2010, 2012). As Gunz *et al.* (2012, p. 300) put it, "Our results support the notion that Neandertals and modern humans reach comparable adult brain sizes via different developmental paths". Those differences could have a major impact on the respective models of brain organization, especially as regards the working memory capacity and the degree of interconnectivity among disparate areas.

All of that leads to proposing some factors that may have played a key role in the emergence of the computational machinery FL makes use

BOX 9. (continued)

human thought and creativity is the mechanism that makes it possible to link two unrelated concepts in order to produce a new concept (double-scope conceptual blending). Language would be a "culturally entrenched means of creating and transmitting blending schemes" (Fauconnier & Turner, 2003, p. 58). This view thus opposes to Chomsky's tenet that it was language that gave rise to human creativity, and not the other way round.

All the aforementioned approaches argue for a social origin of language. Tomasello (1999, 2008), a functionalist-oriented scholar, also shares this assumption. He contends that human cooperative communication derives from the emergence (via natural selection) of social cognition in AMH, which relies on understanding and sharing intentions. Grammar arose through the conventionalization and cultural transmission of communicative tools from an initial stage of iconic gestures (Tomasello, 2008, p. 322), in order to fulfill functional needs: to request, inform, and share intentional attitudes. Therefore, according to Tomasello, language, a socio-cultural elaboration, is not the evolutionary cause of human cognition, but one of its far-reaching consequences.

Other scholars also assume a socio-cognitive origin of language, although in somehow different senses. According to Dunbar (1996), for example, language evolved as a tool for preserving social cohesion. Grooming, the main mechanism related to social cohesion in non-human primates, cannot function when group size exceeds a certain threshold. Dunbar explains language as a kind of vocal grooming that entered the scene once such a threshold was surpassed in hominid evolution.

Other approaches worth considering are the following. Mithen (2005) contends that language derives from ancestral musical abilities, a proposal already advanced by Darwin. Armstrong & Wilcox (2007), Corballis (2002) or Stockoe (2001) have argued for a gestural origin of language, which was subsequently replaced by the vocal channel. Some authors defend that syntactic structure was exapted from the thematic roles provided by the representations of social intelligence (Calvin & Bickerton, 2000), or from syllabic structure (Carstairs-McCarthy, 1999). Another relevant discussion in the field is the nature of protolanguage: whereas Arbib (2005), Mithen (2005) or Wray (1998, 2000) consider that protolanguage was holistic, Bickerton (1990, 2003) or Tallerman (2007) defend that it consisted of discrete units (see Arbib & Bickerton, 2010 for a wide discussion). Rizzolatti & Arbib (1998), Stamenov & Gallese eds. (2002) or Arbib *et al.* (2008) highlight the importance of mirror neurons for key aspects of language like the speaker-hearer parity, and suggest that they could pave the way for the evolution of a gestural language. Deacon (1997) has sustained the co-evolution between language and brain, and Christiansen & Chater (2008) claim that language was an adaptation to the human brain.

Finally, it is worth mentioning the wide use of computer simulations for reproducing the emergence of symbolic systems (Cangelosi & Parisi, 2002; Gong & Shuai, 2013; Scott-Phillips & Kirby, 2010), within models that rely on different assumptions. Accordingly, they attain markedly different results, giving support to both biologically (Nowak *et al.*, 2000) and culturally (Kirby *et al.*, 2008) oriented views on language evolution.

Christiansen & Kirby (2003) and Tallerman & Gibson (2012) provide a full coverage of the main topics language evolution research is concerned with.

of: firstly, the habilitation of the cortical mass required to execute the necessary computations (whether or not linguistic) and, secondly, the overlapping, via connectional invasion, of distant brain areas. As regards the first aspect, the specific growth of cerebral cortex could have provided the working memory space required to carry out the highly complex (i.e. context-sensitive) computations involved in language, which imply hierarchical structuring and both nested and cross-serial LDDs. This means that, once a critical point was attained, the sequences generated by the pattern generator (basal ganglia) could produce mental computations quite beyond a strictly linear computational regime (Type 3), those computations dealing with many disparate activities. As regards the second aspect, the stabilization and consolidation of the overlapping of certain structurally and functionally independent areas brought about by brain growth could transform the computational system into a properly linguistic system (FL), in such a way that such a system worked as an internal communication pathway between sensorimotor and conceptual areas. These changes could perhaps be associated to the speciation process that led to AMH.

A note is in order: although in the computational approach the notion of memory is used in a purely computational sense (i.e. unconscious), and, accordingly, does not characterize any psychological model of memory, like that of Baddeley (1986, 2007), which is accessible to conscious memory, the two notions of memory are not incompatible, for computational memory may be implemented in a number of psychological models. This should be highlighted, because the proposal on the increase in working memory capacity (Balari & Lorenzo, 2013) fits in well with other proposals that, from different premises, have also contended that AMH experienced an increase in the working memory capacity, like those of Russell (1996), Donald (1991), several papers in Wynn & Coolidge (2010) or especially Coolidge & Wynn (2004, 2009) and Wynn & Coolidge (2004, 2007, 2012).

To summarize, from the perspective of this paper, the notion of FLN is not a useful one, for FL (the computational system) is neither specifically human nor specifically linguistic, although language can still be considered to be a species-specific innate trait, this specificity resulting from how its several components are integrated. FL has not developed a specific machinery: it uses a system shared with many other animals; some slight changes operated on the developmental system associated with that system, linked to the development of the cortical structure that supports working memory, gave rise to powerful computations not just involved in language but in other aspects that also presuppose a Type 1 computational regime (i.e. dancing, among many others). Therefore, a little change involving an increase in working memory produced a dramatic qualitative change by which the access to a computational power unknown to date in other species, whether hominid or animal, was reached. This conclusion, a slight change with far-reaching consequences, implies that "language is not a true exception in the natural world" (Balari *et al.*, 2013), and, accordingly, agrees with (1) the recent relevance of the notion of deep homology (Balari & Lorenzo, 2013; Fitch, 2011), (2) the lessons taught by Evo-Devo, and (3) the unspecific view of language brought about by the Minimalist Program (see Box 2).

Info on the web

www.biolinguistics.eu
On-line journal devoted to the biological foundations of language

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News and advances in the biological nature of language

www.biolinguistics.uqam.ca/
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www.facultyoflanguage.blogspot.com.es
Discussion about relevant aspects involved in the faculty of language

http://groups.lis.illinois.edu/amag/langev/
On-line bibliography devoted to language evolution

www.evolang.org/
The main worldwide scientific meeting on language evolution

www.unioviedo.es/biolang/
Two Spanish research projects on biolinguistics (downloadable papers in English)

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