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EVOLUTIONARY SCENARIOS FOR THE EMERGENCE OF RECURSION[2]

At some point in the very recent past, maybe about 75.000 years ago, an individual in a small group of hominids in East Africa underwent a minor mutation that provided the operation Merge.

(Noam Chomsky, 2008)

ABSTRACT: *In the present work we follow the final suggestion made by Hauser, Chomsky, & Fitch, (2002) to consider whether their hypothesis that recursion is the key to human language evolution, in that it is "unique to humans, and unique to language", is consistent with the available evidence from comparative, genetic paleoanthropological and archaeological studies. We contend that it is reasonable to conclude that recursion is uniquely human, although it is not so clear that it is unique to language.*

Keywords: recursion, evolution, spandrel, knotting, cognitive cladogram.

0. Introduction

In their influential paper "The Faculty of Language: what is it, who has it, and how did it evolved?" (from now on, HCF, 2002), Hauser, Chomsky and Fitch argued for a multi-component approach to language, with the goal to distinguish those mechanisms that are also related to other domains of cognition or forms of communication (included under the rubric of a broad faculty of language, of FLB, such as memory or theory of mind) from those mechanism that are thought to be independent from any other cognitive system, and thus specific to human language (narrow faculty of language, or FLN). Among these, recursion was singled out as the core mechanism of FLN, in such a way that it was thought to be the language-specific mechanism that differentiated language both from other human cognitive domains as well as from other communication systems in other animals. In other words, recursion was thought to be unique to language, in the same vein that FLN was thought to be unique to humans.

As HCF claimed, this constitutes a clear program of research in language evolution. It makes clear predictions, that can be empirically studied. In this paper, we intend to

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contribute to this program, by revising the empirical evidence available regarding this double central claim: whether recursion is unique to humans, and whether recursion is unique to language. While there is little doubt that recursion is crucial for language structure, it is not so clear that it is unique to it, given that other human cognitive abilities also seem to involve recursion. In the concluding section of HCF (2002), the possibility that recursion is not even unique to humans was also raised, considering the possibility that recursion might be present in animals in a domain-specific, modular way (for example, just in navigation), and that during evolution, recursion would have become "penetrable and domain-general", and thus applicable not just to language, but also to all sorts of domains (for example, numbers).

Of course, these are empirical possibilities, that call for a broadening of the "research space" HCF considered in their original paper. In this one, we purport to review available evidence on both of these questions, following HCF suggestion: a) whether or not recursion is human specific – whether there is evidence of recursion in other animals; and b) whether or not recursion is language specific – whether it can be found in other human cognitive abilities.

By so doing, we also intend to contribute to clarify the program, against the multiple possible interpretations of their proposal, that have been distinguished by the discussion that followed the publication of their paper. In our view, it is clear that their focus on recursion makes a lot of sense from the point of view of the minimalist program. The main novelty of this program is the effort to reduce as much as possible the core of the language faculty, and displace other linguistic features previously thought to be part of the FLN to the interfaces between the FL and the conceptual-intentional system, on the one hand, and the articulatory-perceptive system, on the other. The fact that the minimalist program in Linguistics was not discussed in HCF (2002), and the fact that the minimalist program is a program, not yet carried out, can help explain the lack of consistency in the very formulation of the proposal for language evolution. Anyway, a proper clarification of the very notion of recursion is required in order to take seriously HCF's program.

This paper is structured as follows: in the first section, we propose an understanding of HCF's proposal that we think makes most sense, as a way out of the conflicting interpretations of their proposal. The second section reviews studies that contend that recursion is also present in other animals, and claims that the evidence doesn't ground this

conclusion. Then, in the third section, we consider an evolutionary scenario for recursion that makes it uniquely human, because of its hominid origins, prior to the split of African hominids into *H. neanderthalensis* and *H. sapiens*. Finally, in the fourth section, we consider the possibility that recursion appeared not directly in the context of a faculty of language, but in relation to more basic motor skills, such as knotting and netting. Archaeological evidence suggests that *H. sapiens* were clearly capable of knotting and netting, activities that might involve recursive patterns. The difficult question that arises at this point is the connection between such recursive abilities and recursion as a component of the faculty of language, but it opens up a new avenue of possibilities.

1. On how to understand the program

In their seminal work, HCF proposed a hypothesis that has provoked one of the most intense debates in the last three decades about the origins of language and the language faculty. Through such debate (Fitch, et al. 2005; Jackendoff & Pinker, 2005; Pinker & Jackendoff, 2005, among many others), it has become clear that the proposed program is not obvious or easy to accept. A great deal depends on how precisely their claim is stated, and the additional assumptions one takes for granted. In fact, part of the problem has to do with the lack of precision and consistency in the way the program was formulated; as a matter of fact, in HCF we already find several different definitions of what they call the faculty of language in a narrow sense (FLN) – the components of the language faculty assumed to be language specific -, and the role of recursion in it:

> "We hypothesize that FLN only includes recursion and is the only uniquely human component of the faculty of language" (2002:1569, abstract).

> "We assume, […], that a key component of FLN is a computational system that generates internal representations and maps them into the sensory-motor interface by the phonological system, and into the conceptual-intentional interface by the (formal) semantic system. […] All approaches agree that the core property of FLN is recursion" (2002:1571, col.1).

> "In fact, we propose in this hypothesis that FLN comprises only the core computational mechanisms of recursion as they appear in narrow syntax and the mappings to the interfaces" (2002:1573, col.2-3).

> "At minimum, then, FLN includes the capacity of recursion." (2002:1571,

col.3).

Recursion is sometimes claimed to be the only component of FLN, while others is viewed as "one among others". On the other hand, recursion sometimes is presented as a computational mechanism that generates a hierarchical structuring of elements, while at some other points seems to be inextricably constituted by the mappings of such elements to the phonological-articulatory and the conceptual-intentional levels of cognitive representation which the syntactic component pairs. Thus, the first statement singles out recursion as the only component while fourth one suggests it is one among many; the second, on its turn, decouples recursion from the mappings of it generates to the interfaces, while the third seems committed to the view that the recursive component is to be characterized by the sort of input-output interface representations to which it applies.

From the point of view of the minimalist program, though, it is clear that the interpretation that makes most sense is the one that takes recursion in the abstract –as a mathematical function that takes units and combines them into hierarchical structures. In fact, the idea is that a "merge" operation is enough to account for all sorts of linguistic structures (Chomsky, 2010)**.** From the point of view of the minimalist program, there is a clear sense in which recursion is understood as the one and only computational mechanism that generates expressions, which happen to be linguistic because of the interface systems – the phonological-articulatory and the conceptual-intentional ones- to which this expressions map[3]. The goal that drives the minimalist program is to reduce at a minimum what's thought to be constitutive of syntax, by trying to derive as much structural properties of external language from the constraints imposed by the interfaces. To put it in Chomsky's terms, the hypothesis is that "Interfaces + Recursion = Language" (Chomsky, 2010). From this point of view, several voices in the debate have understood HCF from this minimalist standpoint:

> *"Hauser et al. (2002a), for example, continue to claim that grammatically structured languages are unique to the human species, but suggest that the only*

3 Notice also that, as regards the functional characterization of recursion, it is the linguistics/computer science notion of recursion that matters, not the meta-mathematics understanding of recursion, as Fitch (2010) has clarified. The former notion is the one relevant for hierarchical structures, while in meta-mathematics they talk of recursive functions in a very broad sense.

component of the human language faculty that is, in fact, uniquely human is the computational mechanism of recursion" (Penn, et al., 2008)

"A recent proposal (Hauser, Chomsky & Fitch, 2002) suggests that the crucial defining property of human language is recursion." (Parker, 2006)

"Within this shared FLB is what they call the 'faculty of language in the narrow sense' (FLN), consisting only of recursion."(Stebbins, 2007)

There is a source of ambiguity in Chomsky's characterization of the program, though, depending on how the connection between recursion and the mappings is conceived. Thus, it is possible to view the recursion component in the abstract, quite apart of the lexical elements to which it applies to generate syntactic structures, which then receive, through the mapping to the conceptual-intentional interface, a logical form that constrains its propositional content, as well as a phonological serialization through the mapping to the articulatory interface, which allows for their transformation into a sequence of motor patterns. But it is also possible to view the recursive mechanism as intrinsically constituted by the interfaces to which it connects; in this interpretation, recursion is taken to be constitutively a linguistic mechanism.

Thus, the risk of misinterpreting HCF's proposal is high. However, in their response to Jackendoff & Pinker (Fitch, Hauser, & Chomsky, 2005; henceforth FHC), they offer further clarification by considering the possibility of an organism which could show *recursion* but that instead would lack the (same) human mappings that humans theoretically show. We take it that this is evidence that the intended understanding of the program is to consider recursion in the abstract, as a computational mechanism which generates hierarchical structures of elements – whichever elements it happens to apply to, be them navigational patterns, sounds, musical tones, numbers, or, as we will also consider in section (4.2), manual skills. For the very hypothesis that recursion could have appeared in evolution quite apart of language – a conceivable possibility if the hypothesis that it appeared in fact just for language is to be an empirical hypothesis-, an abstract understanding of recursion has to be taken for granted. Otherwise, the characterization of recursion as unique to language would be question-begging. Henceforth, this abstract reading of recursion is the one we propose to accept in order to assess whether recursion is

"unique to humans, and unique to language". In this way, we will be able to consider whether there is evidence of recursion in some birds calls, as claimed (Gentner et al., 2006), or in our ancestor practices of netting and knotting (Adovasio,et al., 1997; Adovasio, et al., 2005). In general, our goal is to confront HCF program with the data from other evolutionary study fields, and discuss whether it fits well: as regards cladistics and systematics, is FLN, so conceived, a human autapomorphy (a human only evolutionary change) or is it instead a homoplasy (an evolutionary change appearing in parallel in two non-related species)? Is recursion language specific or can we find evidence of recursion in other cognitive abilities? If the latter is the case, are these cases in some form parasitic on language and linguistic recursion (so that they were made possible by the emergence of language? Or are they rather more basic or independent of language? To the revision of the evidence we now turn.

2. Data from comparative studies: homoplasy, apomorphy or autapomorphy?

The comparative perspective has proved to be a very fruitful method. The so-called *habituation-dishabituation*[4] method aims to present some kind of input with human intervention reduced *ad minimum,* so that the participant's output or answer is as natural as possible. In other words, this research method intends to avoid conditioning as far as possible. Its implementation into evolutionary linguistic studies is useful for testing the idea that most if not all components of human language can be found in other species, above all primates, and to establish what is unique to *H. sapiens*. Thus, language is more than just words. It involves to structured patterns, it shows rhythm, phonology – and hence, phonological categories, which are cognitive entities -, it is based on the merger of structures and complex thoughts, reflections we make every day. Keeping this in mind, such variety of converging elements and applying the *habituation-dishabituation* method to their study, it has been possible to draw some conclusions about cognition, its evolution, and more specifically about language.

2.1 Cognitive micro-abilities and cognitive cladograms

There are two classic examples of how the comparative approach has proved useful in establishing whether a particular feature is uniquely human or not: rhythmic discrimination and categorical discrimination. The latter was put to the test three decades

4 It is also called "familiarization-discrimination method".

ago and it has been proven that chinchillas are able to distinguish categorically within alveolar plosive consonants, namely [t] and [d] (Kuhl & Miller, 1975). This is also true for a new world primate, the cotton-top tamarin or *Saguinus oedipus* (Ramus, et al., 2000).

Regarding rhythmic discrimination, Nazzi et al. (2000) showed that American 5-month-old children can distinguish two languages on the basis of the rhythmic class, even when those languages belong to different rhythmic classes. Tincoff et al. (2005) have shown that the ability[5] for language discrimination possibly predates our first known *Homo* ancestors - *H. erectus*[6]. In their experiment, cotton-top tamarins could discriminate between languages belonging to different rhythmic classes (e.g. Dutch vs. Japanese). Finally, Toro et al. (2003) published similar results with common mice (*Mus*). Though both non-human mammals had problems when discriminating between languages of the same rhythmic class, it became clear that this ability, that modern humans use for language, was present in a species separated from the hominid ancestors 70-80 millions of years ago (mya). Interestingly enough however, all three species – humans, mice and tamarins - were unable to discriminate between languages when sentences were presented backwards, something that indicates a possible loss of relevant acoustic information.

In particular, the categorical perception results require a revision of the assumption that it was a human-specific ability, and hence, something to be accounted for in evolutionary terms within the hominid lineage. In the same vein, we have tried to reconstruct which language-related abilities are present in which species through a cognitive cladogram (Nadal et al., 2009), reproduced here as fig. (1) but modified with some new data and new species.

Finally, some general aspects of linguistic morphology could have been found in other non-humans primates. Recent reports suggest that human language affixation could also have evolved before the split of the common ancestor of humans and tamarins (Endress, et al., 2009). These results increase the number of general elements that should be regarded as components of FLB and isolate even more recursion as something special to human language. Curiously, some months after the publication of this paper, Ouattara, Lemasson, & Zuberbühler (2009) have published the results of a field study that consisted in observing the alarm call system of Campbell's monkeys, which suggest that this species

5 We use the term “micro-ability” or ability because these species have experimentally shown to be capable to do that.

6 We here adopt Wood & Collard's (1999) proposal for transferring *H. habilis* and *H. rudolfensis* from the genus *Homo* to the genus *Australopithecus*.

uses an analogue of human morphological suffixation. For reasons of scope, we do not review this issue here, but simply advance our doubts about the supposed "morphemes" found and analyzed by the authors. Neither the Campbell's monkeys calls nor their supposed morphemes seem to be what linguists call morphemes: cognitive entities very well structured and demarcated as concerns lexical-semantics, lexical-syntax and clear referentiality[7].

We can see that abilities that today are language-related in modern humans are retraceable several mya. Most of them can be roughly divided in three main groups:

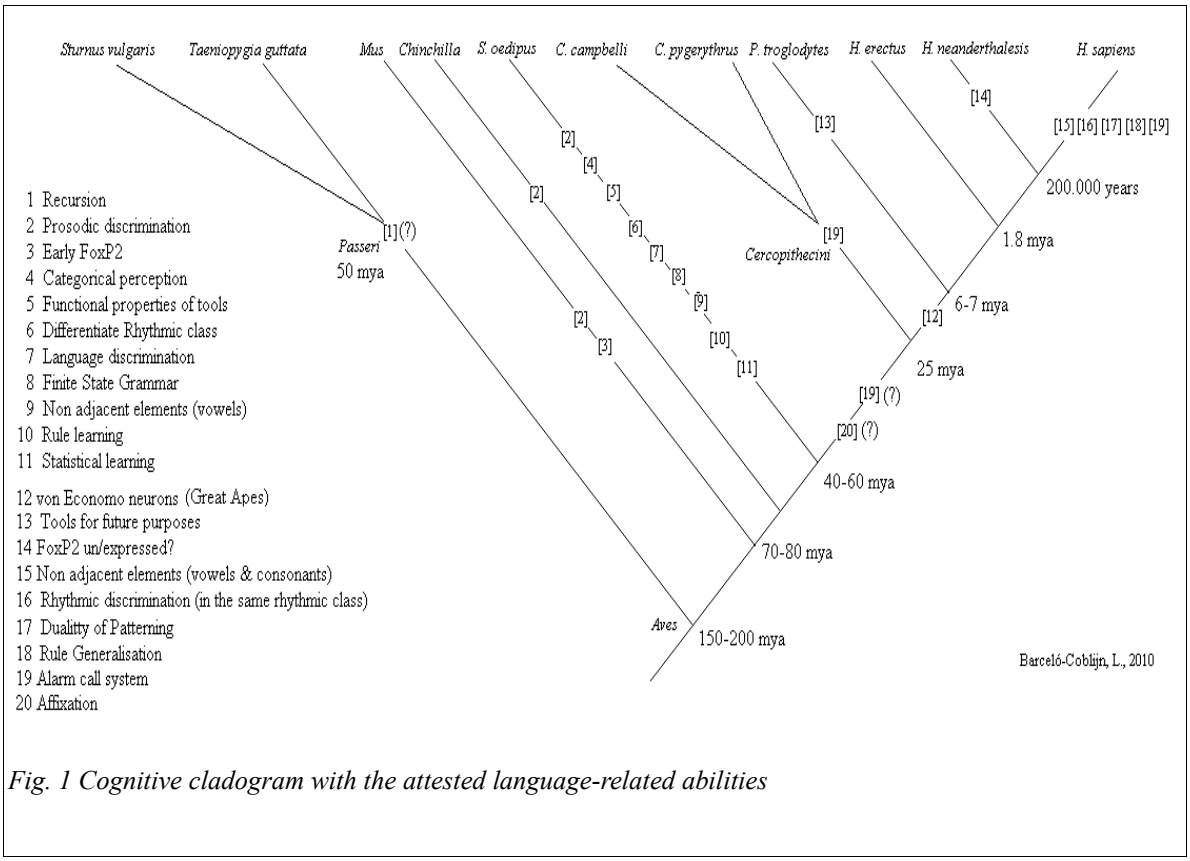

Fig. 1 Cognitive cladogram with the attested language-related abilities

language perception abilities, language learning abilities and language computational abilities. The latter group of abilities is the most interesting for linguists sympathetic to the minimalist program, which seeks to clarify, among other aspects, the computational features that govern linguistic structures, as they are viewed as the very human cognitive innovations. Note the tentative character of the cladogram: not all species have been put to test for the same abilities and hence, there are still "gaps to be filled".

7 Cf. number 20 in the cognitive cladogram of fig.1. These doubts have been reflected therein with a question mark, as well as in the case of recursion.

2.2 Recursion and experimental research

As we have commented above, for HCF *recursion* is the most important cognitive innovation affecting language. Fitch & Hauser (2004) aimed to test this assumption in an experiment that showed tamarin monkeys series of sounds with recursive and non-recursive grammars. Their results were interpreted as that tamarins were unable to process patterns of Phrase structure Grammars[8]. Due to the fact that this has generally been interpreted as a test for recursion, this experiment motivated a vast debate about the adequacy of the Phrase Structured Grammars – the highest in the Chomsky's Hierarchy (cf. Fig 2, below)- representing human linguistic capacity, given the low results scored by humans in some experiments (Coleman, et al., 2004; van Heijningen, et al., 2009; Kochanski, G., n.d.; Liberman, 2004; Perruchet & Rey, 2005; de Vries, et al. 2008). However, recent empirical work carried out by Gentner et al. (2006) showed very interesting findings challenging HCF's original hypothesis, if the experiment can be accepted as a test for recursion (contra Fitch, 2010; cf. footnote 8): under training, starlings (*Sturnus vulgaris*) were able to process and master species-specific song patterns, which were structured according to the specificities of a Context-free Grammar. These kinds of grammars belong to the second level of Chomksy's Hierarchy and differ from first level ones because they make use of recursion[9]. Instead, according to the traditional vision of computer science and formal language theory[10], the first level, the so-called Finite State Grammars, are *iterative,* not recursive, and hence, computationally less powerful in

8. Curiously enough however, there is one important aspect of this experiment that is not usually commented on, even in linguistics: in some sense, we can say that this experiment was a first implicitly attempt to the *Pumping lemma* test. The adequacy of a grammar to this lemma is what determines whether a grammar is recursive or not. Fitch has repeatedly declared that that experiment was not a test for recursion, contrary to the general interpretation (cf. specially for this issue Fitch, 2010 and footnote 10 in this work).

9 Note the inclusion relation the grammars maintain within each other, in a Russian-dolls manner, and how this could induce gradualist arguments regarding the evolution of syntax.

10 Fitch (2010, p.87) states that "this notion that A^n B^n requires recursion is incorrect,.[...] In formal language theory, A^n B^n is generally accepted (at least since Chomsky 1957) as a canonical grammar beyond finite-state capabilities, an nothing else. Although one *could* implement A^n B^n recursively, one can also implement it iteratively without recursion […] the $(AB)^n$ grammar could also be implemented recursively. […] The crucial factor […] is that it requires some additional memory mechanism(s) to keep track of "n"". Notwithstanding, if the whole experiment boils down to a memory task, the role of the different types of grammars might be considered irrelevant for non-human animal cognition, according to a more psychological approach.

generating structures.

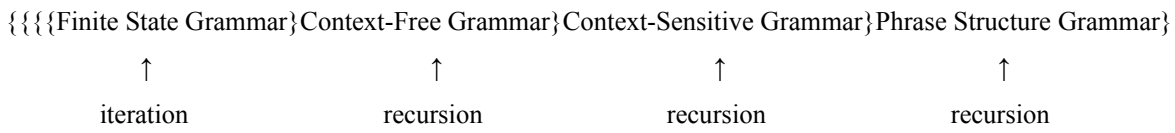

Fig. 2 Chomsky's Hiearchy and the mechanisms that are traditionally linked to them.

Anyway, the discussion about the adequacy of PSG for representing human language is justified since Fitch & Hauser (2004, p.378 col.1) state that "*grammars above FSG level, are, minimally, a crucial component of all human languages*". Thus, the debate on which grammar describes better human language is still open to new inquiries.

Given this evidence, a non-trivial question arises: is recursion an apomorphy - a change that appeared in the hominid lineage - or is it instead a homoplasy - a change appeared in parallel in both *H. sapiens* and *Sturnus vulgaris*?

Note that if we understand that in FLN there is only recursion – as the most popular version of HCF's hypothesis seems to tell us (cf. section 1) - , one could also think that Gentner's et al. results falsifies it. Nevertheless, even accepting such a version, some caveats are necessary before calling HCF's proposal into question: firstly, in Gentner's et al. experiment a very different method was followed, since starlings underwent hard training - something that frontally clashes with the habituation-dishabituation method. Secondly, the kind of stimuli used, were quite different: whereas Fitch and Hauser used human linguistic stimuli, Gentner et al. used species-specific sounds. Additionally, a recent work published new data on the ability of song birds - concretely zebra finches (*Taeniopygia guttata*) - for processing and mastering recursive patterns, that seem to be at odds with the results of starlings: finches could have just attended to the different order of the elements (van Heijningen et al., 2009). Van Heijningen and collaborators argue that the acquired discrimination by zebra finches could be based on phonetic rather than syntactic generalization and hence, much of the same could be applied in Gentner's et al. experiment.

In this section we have commented on the most relevant tenets of the habituation-dishabituation method applied to human language research. As we have shown, these studies suggest that some basic micro-abilities - today language-related in humans – could have originated a long time ago, when mammals began speciation and split into several

different groups of living beings. But more importantly, they suggest that several of these abilities are unlikely to have evolved "for" language, since all these mammals have no kind of linguistic system comparable to that human language. It is highly doubtful, though, that these "precursors" for language already present in other animals, include recursion as a generative mechanism.

3. On population genetics. The spandrel theory

Reconstructions of the Neandertal vocal tract and other attempts of physiological reconstructions aside[11], it is clear that recursion cannot fossilize. However, indirect data from other scientific fields might help us to estimate the approximate date of the appearance of such a cognitive trait. Let us review some relevant data on evolutionary studies in order to build some bridges between biolinguistic theory and paleogenetic and archaeological data.

3.1 On the African origins of human cognition

According to mathemathics, there are different kinds of formulas that describe different recursive patterns[12]. Different kinds of recursion have been found in nature, e.g. the well-known Fibonacci series found in the order of the seeds of sunflowers. However, an important difference between this very basic kind of recursion in sunflowers and the kind of recursion argued to be present and functional in human language is - besides their generative power – that linguistic recursion is something that is overwhelmingly active in language. Sunflowers do not create new Fibonacci patterns, but it is somehow encoded in their genomes. Instead, humans create new recursive linguistic patterns every time they speak (and *think,* according to an internalist view). It seems fair to say that, wherever it takes place in the human brain, recursive patterning is the result of some kind of neural interaction. It appears as an active and productive cognitive mechanism. Something has changed in the neural circuitry or functional neuroarchitecture[13] of *H. sapiens* that favors recursive patterning, chaining thoughts in a complex manner and, ultimately, it might favor the making of complicated calculations too. But when did it appear in the long history of evolution? In the great apes clade? During at some point of the genus Homo?

11 For the issue of larynx reconstruction and larynx functions, cf. among many others, (Boë, et al., 2002; de Boer, 2007; Fitch & Reby, 2001; Fitch, 2002; Honda, & Tiede, 1998; Lieberman, 1973; Lieberman & Crelin, 1971; Lieberman, et al., 1969)

12 Cf. "Recursive Functions" (Stanford Encyclopedia of Philosophy, n.d).

13 I here refer both to a possible change in structure as well in function. They are not mutually dependent.

We are convinced of the universal presence of "the recursion mechanism" in *H. sapiens*[14]. As Rebecca Cann and colleges showed, it has been possible to retrace the distinct human *haplogroups* until their first and unique place of origin in Africa (Cann, et al. 1983). This and subsequent work in population genetics lent strong support to the so-called *Out-of-Africa* theory, which states that the whole of modern humanity comes from a single place, probably in Kenya. These studies have received support from the male counterpart, the Y chromosome (Capelli et al., 2001; Chiaroni, et al., 2009; Stumpf & Goldstein, 2001). The large – and sometimes rapid, as it seems to be in the case of America and Polynesia – human expansion could have started 200.000 years ago (kya) according to recent analysis of coalescence made by Kaessmann, et al., (2001). Their analysis also points out that, in comparison, the DNA sequence variation of *Pan troglodytes* (chimpanzees) is several times greater than that of *H. sapiens*. Thus, the genetic diversity within modern humans is so low that it suggests there was, from the beginning on, a very small group (probably as the authors suggest, the result of a population bottleneck; realistic models used by the authors talk about 3.700 individuals), that suffered a rapid expansion throughout the world. Moreover, if all languages show recursive patterning, this is an indirect parsimonious indicator that probably the first modern human language also showed recursion. The possibility that it has later evolved in different – sometimes unconnected – communities all over the world (being so homoplasies), seems implausible to us. Thus, we speculate that a drastic population bottleneck, as Kaesmann's et al. analysis suggests, would have indirectly supported the spread of the recursion mechanism – if it was still not yet a common feature present in both neandertals and sapiens; cf. section four below - throughout the, at that time, small community.

Altogether this evidence leads us to a preliminary parsimonious scenario: the recursion mechanism – being the fruit of either a genetic change, or a development change or, most probably, both - was a common cognitive feature in, at least, *H. sapiens* previous to the expansion from Africa. In other words, most if not all members of this reduced group

14 Its argued absence in Pirahã (Everett, 2005) deserves more attention and analysis. In this respect, Fujita claims that it would not be a problem; it could be universal in humans, but some languages might not make use of recursion: "*I see no deep conflict between his [Everett's] data and the generativist claim that recursion or embedding is an innate and universal property of human language. In any case, for something to be part of U[universal]G[grammar] it does not require that it be observed in every particular language, extant or extinct*". Fujita (2009, 141; square brackets added, LBC).

shared the same cognitive (linguistic) endowment. In the next sections we shall comment on whether or not we can say much the same thing concerning Neandertals, and hence talk about a much earlier scenario for recursion (before both hominids split off). Next, we review the theory that could accommodate a sudden autapomorphic (an apomorphy exclusive of a species) rising of recursion in *H. sapiens*.

3.2 On Gould & Lewontin's spandrel theory

Gould & Lewontin (1979) oposed an adaptationalist understanding of the theory of evolution, by pointing out that it can give rise to mistakes by attributing functionality to features that may just be the outcome of structural constraints. In this regard, they recall Darwin's words about the possible number of factors that influence evolution[15] beyond natural selection, showing that Darwin himself did not believe that natural selection alone could explain any biological trait. The main critiques to the radical view of the *adaptationalist* program are devoted to the sequence that, in Gould and Lewontin's view, this program typically follows:

1) An organism is atomized into "traits" and these are explained as structures optimally designed by natural selection - on the contrary, Gould & Lewontin believe that organisms are integrated entities, not collections of discrete objects.

2) An organism cannot optimize each part without imposing expenses on others - the authors see here the introduction of the notion of "trade-off". In other words, if an organism improves an element, another one becomes worse than before, following a kind of "compensation" rule.

3) Adaptationalism usually assumes that if one adaptive argument fails, another must exist; its absence is due to the fact of an imperfect understanding of where an

15. *"But as my conclusions have lately been much misrepresented, and it has been stated that I attribute the modification of species exclusively to natural selection, I may be permitted to remark that in the first edition of this work, and subsequently, I placed in a most conspicuous position -- namely, at the close of the Introduction -- the following words: "I am convinced that natural selection has been the main but not the exclusive means of modification."*

This has been of no avail.

Great is the power of steady misrepresentation; but the history of science shows that fortunately this power does not long endure."

Darwin, (1870) final chapter of the sixth edition of *On the Origin of Species.*

organism lives and what it does. This program also emphasizes immediate utility and excludes other attributes of form.

Against this programm, Gould & Lewontin propose the concept of spandrel, a term borrowed from architecture, which defines the particular space that always arises between two arcs. They observe that this space, more or less triangular, is a necessary by-product of vaults. There is no possibility of avoiding it, if one implements two arches. Hence, it would be wrong if, following adaptationalism, one was to take for granted that spandrels are there for some function: some feats cannot be explained functionally but structurally. As a consequence, authors apply this notion to biologic evolution and consider the possibility that sometimes, changes obey to structural necessities and that the use these new changes will have is a secondary effect, for reasons of architecture, development or history. Finally they assert that "the immediate utility of an organic structure often says nothing at all about the reason for its being".

Both Bickerton (1996) and Gould (1997) have alluded to the concept of spandrel as a possible explanation for language emergence in humanity. Johansson (2005) points out correctly that Chomsky has also said something about it but without any clear detail about the "spandrel theory", and quotes Chomsky (1988) as the closest he comes to this issue, but, in Johansson's view, in an "openly skeptical" manner regarding "the power of Darwinian evolution to bridge the gap"[16]. In this regard, there is a clearer precedent in an interview in the early 80's by Huysbregts and Riemsdijk (Chomsky, 1983). Concerning the spandrel option, Fitch (2005, p. 216-217) makes the following reflections:

> *"From the perspective advocated here, fractionating language into multiple interacting components, it is clear that the mechanisms compromising the FLB as a whole cannot be a spandrel. […] For something as recently evolved as language, and given the abstractness of many characteristics of language that interest linguists (such as recursion or subjacency), it would be surprising indeed if none of them were spandrels, in the sense of remaining unchanged from an initial exapted state. […] To demonstrate empirically that linguistic recursion is not a spandrel, we would need to show that it both functionally entails, and mechanistically exhibits, characteristics not found in social mindreading*

16 On the contrary, what we see is skepticism about a *gradualist* evolutionary explanation for the emergence of language and based on Natural Selection only: *"Evolutionary theory is informative of many things, but it has little to say, as of now, of questions of this nature [such as the origin of language]. […] In the case of such systems as language or wings it is not easy even to imagine a course of selection that might have given rise to them (Chomsky, 1988, p. 167).* (quoted in Johansson, 2005, pp.161)

recursion."

Such empirical proof has still not been found, therefore it is still reasonable to consider the possible spandrel nature of recursion. It would then be the result of mutation(s) and/or developmental changes – in this respect, we maintain an agnostic point of view; the quotation at the beginning of this work loosely treats this issue, but we shall not analyze what Chomsky meant with "minor mutation", being those the last lines of the epilogue of his manuscript.

The problem of considering as a spandrel the neurocognitive apparatus that allows possible a potentially massive production of structured mental structures, is that again, this explanation leads to the following question: if a spandrel is the by-product of a very specific combination of elements that always yields a final structure, what are the neurological and/or genetic building elements that provoke the recursion side-effect? Which are the arches provoke the unexpected emergence of recursion?

On the other hand, the data offered by genetics on the temporal points of separation between sapiens and neandertals stress the fact that great qualitative differences in cognition would have been yielded by *H. sapiens* in a seemly short span of time. To short in fact, to make a genetic mutation the only responsible; regarding this, FHC (p.206) make the following statements more in tune with the Evo-Devo program:

> *"If it turned out that the capacity for recursion resulted from a phase transition in the pattern of neural connectivity that results automatically from increases in neocortex to subcortical tissue ratio, interacting with standard mammalian brain development, this would certainly be an interesting result"*.

4. Recursion before the split between *H. neanderthalensis* and *H. sapiens*?

How, then, does the spandrel hypothesis fit the available data from anthropological genetics? What can genetics tell us about the probable points of separation, speciation or emergence of *derived traits*[17] in *H. sapiens*? In Clark (2008) we find a genetic tree with different dates suggesting that just 200.000 years would have been enough for speciation (fig.3). Although the last common nuclear DNA ancestor of both neandertals and sapiens

17 In phylogenetics, a trait is derived if it is present in an organism, but was absent in the last common ancestor of the group being considered. This may also refer to structures that are not present in an organism, but were present in its ancestors, i.e. traits that have undergone secondary loss. Here the *lack* of a structure is a derived trait: e.g. the lack of laryngeal air sacs in *H. sapiens*. Hence, recursion might be such a trait.

can be found 706.000 years ago, the separation event of both populations (or what's the same, the undergone speciation process) was 370.000 years ago. The mtDNA common ancestor for modern humans is dated 171.000 years ago. In the meantime, that is ~200 kys (370 kys minus 171 kys), several different changes took place in both genomes[18] and/or developmental processes. One of the results was that *H. sapiens* developed a cognitive mechanism that allows them to cognize embedded structures, which are arguably applied in music, language or maths. Did neandertal's divergent and isolated evolutionary path go in the same direction?

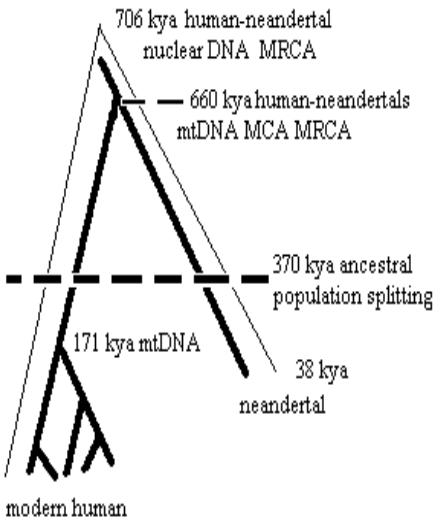

Fig.3 Genetic tree representing the dates the Most Common Recent Ancestors (MCRA) and speciation of neandertals and modern humans. Based on Clark (2008).

The more or less brief span of time between the split event and the mtDNA common ancestor gives us ~200 kys, during which archaic *H. sapiens* would have developed the cognitive faculty of language until they reached the current human language. For that matter, the spandrel theory within an Evo-Devo conception, could be applied to recursion, conciliating the brief span of time with the apparently abrupt and unexpected emergence of this biological innovation in modern humans proposed in HCF and FHC; a new change that would have rewired an important part of cognition, making possible not only the use of a powerful communication system, but also – if finally confirmed – other skills that might have been improved thanks to recursion, like complex mathematical calculi or knotting. But this still does not clarify the moment in which this cognitive trait appeared.

18 Not much, since both species share 99.5% of the genome.

4.1 Genetic similarities between H. neanderthalensis and H. sapiens

It is perfectly possible to conceive neandertal individuals sharing recursion with their sapiens cousins, as it is reflected in cladogram (a) in fig. (4).

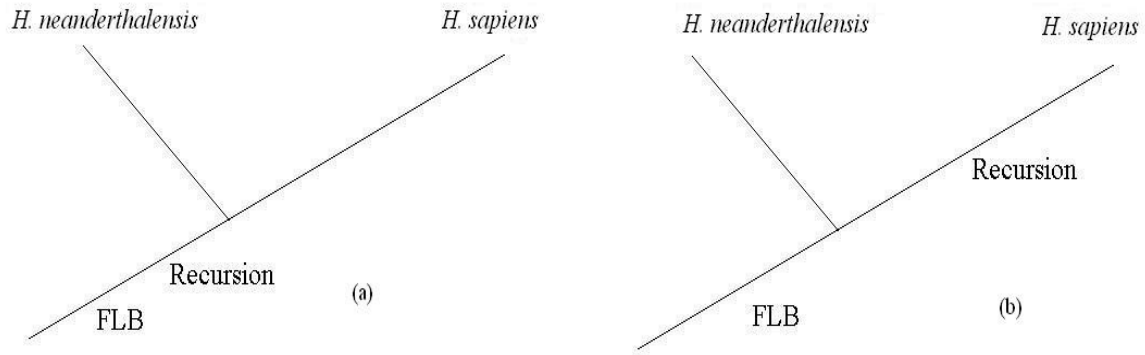

Fig. 4: Cladograms representing two possibilities for the emergence of recursion: before and after Neandertals and Sapiens split off.

The first neandertal genetic data come from short sequences of mtDNA obtained from the humerus of the type specimen by Krings et al. (1997). The first conclusions about such ancient DNA were that those sequences fell outside the range of variation of a diverse sample of modern humans. Interestingly, neandertals might have had a similar rate of genetic diversity to that of sapiens - mentioned in section 3.1 - that is, small, as Krings's et al. (2000) experiments point out. And these are not the last coincident points between these two hominid species: experiments have shown that both species shared the same amino-acid sequence of the Fox-P2 gene (Krause, et al., 2007), a similar blood-group O (Lalueza-Fox et al., 2008), - though both were different to that of chimpanzees (Kermarrec, et al., 1999)-, even a similar (though independently evolved) melanocortin receptor, which regulates pigmentation in humans and vertebrates or, in other words, some neandertals were also red-haired (Lalueza-Fox et al., 2007). Thus far, the coincident features between modern *H. sapiens* and *H. neanderthalensis* are several and could even be more than previously thought. Quite importantly, recent results from mtDNA seem to have solved a debate about several hominid remains found in Uzbekistan and in the Altai region of Siberia. Morphological analyzes were not conclusive and both interpretations – either Sapiens or Neandertal – had been proposed. Krause et al. (2007) have shown that those remains belong to a *H. neanderthalensis* of 37,750-years-old and 43,700-years-old

respectively. These results imply that the traditionally accepted neandertal border has to be extended 2,000 km to the east, making the theory of a colonization of (part of) Asia by *H. neanderthalensis* more feasible. However, it is important to keep in mind the fact that up until now, no genetic contribution has been found from the neandertal genetic pool to the modern human genetic pool,- (Caramelli et al., 2003; Krings et al., 2000, 1997; Lalueza-Fox et al., 2006; Serre et al., 2004), though it is still possible that it will be found- as Pääbo has repeatedly warned[19]. Therefore, arguments in favor of coincident cognitive capabilities like recursive patterning should retract themselves to a temporal point previous to the split between these two hominids.

Summing up, available genetic data suggest some relevant insights about the evolution of language: 1) an African origin for modern humans and hence for language can be argued; 2) these data do not imply nor exclude an earlier emergence of recursion, due to their great genetic similarities; 3) but, if recursion is a sapiens autapomorphy, there is need of an explanation that can account for such a sudden change (cf. section 3.2 for a possible one); 4) recursion does not need to be *per se* the (by-)product of mutation only, since, in combination with genetic change, there could have been developmental changes too.

Still in the Upper Paleolithic, we explore next some possible samples of recursive behaviour in that time, in order to find some archaeological traces of recursion.

4.2 Recursion and archaeological record.

If we still cannot target the genetic and or developmental change in modern human DNA that favored the great leap in human cognition, maybe we could find traces of that in the archaeological record. Regarding recursion, there are obvious difficulties in finding and showing its presence, since it does not fossilize. We recall here FHC's words about the range of action of recursion:

19 In this respect it is worth bearing Clark's words (2008) - suggesting three possible scenarios - in mind:

1) *If there had been admixture, say 100,000 years ago, giving, modern humans small segregating pieces of our genome with Neanderthal ancestry, it would be nearly impossible to identify them as such, even with full genome sequences.*

2) […] *Nordborg (1998) pointed out that mtDNA follows clonal haploid transmission, and so the genealogy inferred from mtDNA is only one sample among millions of possible genealogies. Admixture could have easily occurred without leaving any trace in current mtDNA sequences.*

3) [...] *Also, perhaps the interbreeding was strictly unidirectional; for example, only human female by Neanderthal male matings occurred and never the reverse. This would yield modern humans with admixed nuclear genes but a complete absence of Neanderthal mtDNA.*

> *"Accepting for a moment our provisional, tentative assignment of FLN of only recursion and mapping to the interfaces, it seems clear that the current utility of recursive mental operations is not limited to communication."* (FHC 2005: 186)

Hoffecker (2007) argues that it is possible to recognize recursive behaviour in Middle Paleolithic artifacts which correspond to the Levallois technique:

> *"At this site [Biache-Saint-Vaast, France], blade-like flakes of predetermined size and shape were produced by a hierarchically organized sequence of removals from a prepared core […]. Variations in the direction and size of the flake removals reveal some recursive combinations within the embedded hierarchical levels."* (Hoffecker, 2007, p.371; square brackets added, LBC)

However, as the author himself recognizes, "prepared core technology has late Acheulean roots"; Cela-Conde & Ayala (2007) comment that "*The Levallois technique appeared during the Acheulean period, and was used thereafter. Its pinnacle was reached during the Mousterian culture.*" Thus, this material culture flourished in Europe and the Near East, therefore there has repeatedly been a consistent identification between the Mousterian culture and *H. neanderthalensis*, despite the inherent difficulties in associating a given species with a cultural tradition. In other words, Hoffecker's approach would imply that neandertals could have made some use of recursion. It is true that this general conception about the systematic link between neandertal-Mousterian has been questioned after the excavations carried on in the Near East, where a posterior occupation by *H. neanderthalensis* was certified, at sites which had already been inhabited by anatomically modern humans (Bar-Yosef & Vandermeersch, 1993).

According to Hoffecker, some tools like *scrappers* would have been made following some kind of recursive process; in his proposal, he appropriately interprets an order of the flaking process that such tools suffered. Nevertheless, beyond the enumeration of some of the hits, it has not been offered any system or model that fully explains the manufacturing of the tools and that convinces us that the same kind of recursion is used in both language and tool making. Though we admit a coincident intuition regarding recursion and tool making - that is, it should, in fact, be possible to infer recursion in some non-linguistic behaviours - further research is required in order to assess that the same cognitive mechanism is acting in both modern human language and Mousterian tool manufacturing.

4.2.1 Recursive patterning in knotting and netting

An additional problem in this kind of approach has been put forward by Camps & Uriagereka (2006) in their study on knotting. Taking into account an intuition left on a draft by Mount (1989) - according to which knots could be developed by some kind of Context-sensitive grammar (a fortiori, by a recursive grammar) - Camps & Uriagereka try to answer the following questions: is this kind of grammar the only one able to process an activity like knotting? What about other hominids? Is there available proof of knotting beyond the Upper Paleolithic? The authors contend that Context-sensitive (when recursive) and Finite-state (iterative) grammars do not yield the same results. The difference is that the latter needs more memory and steps to yield the same endpoint. In other words, recursion would be clearly beneficial for complex activities like knotting. The second conclusion is that, while there is proof of knotting in the Upper Paleolithic that can be attributed to anatomically modern humans, this is not true for neandertals. According to Camps & Uriagereka, there is still no clear evidence that the hafted Mousterian points were attached to wooden shafts by means of knots. Indeed authors argue that "*Mousterian projectile technology implies hafting, but not obviously the ability to make knots; in contrast, when it comes to the M[iddle] S[tone] A[ge] projectile technology, use of knots can arguably be inferred*."(Camps & Uriagereka, 2006; p.52).

Interestingly, d'Errico (2003) shows that the *hafting* technique is not an innovation of modern humans, given that traces of *bitumen* have been found at several Mousterian sites from Levant[20], a kind of glue material used for hafting. D'Errico points out that in Near East there are clear evidences of hafting, blades and burials which can be attributed to both species (cf. d'Errico 2003, Fig. 8, p.200). The Near East seems to be a place where both species might have been in touch with each other and even might have coexisted in some areas. Whether there was a transfer of cultural traditions is still contentious[21]. Moreover, an associated activity like netting is only found in anatomically modern humans sites (Adovasio,et al., 1997; Adovasio, et al., 2005).

Species do not always exploit all their potential and capabilities simply because it is not always required by the environment. Experiments carried out with apes and monkeys have shown that the capabilities of these primates are greater than those exhibited in

20 Paleoanthropologists call "Levant" the area of the current Near East, then it was the the Levant of the "Neandertal's land".

21 Cf. d'Errico, et al., (1998) for an interesting debate about whether or not there was Neandertal acculturation in Western Europe caused by the arrival of modern humans.

natural conditions[22], although it is true that several of the possible behaviours have only been found in labs. However, even if neandertals could have been capable of knotting, it is also true that this is a complex process that has been exploited in some cultures more than in others. On the one hand, some cultures placed in the vicinity of great volumes of water have developed a very intriguing and complex collection of knots, very useful for fishers. On the other hand, other cultures like those of the Aborigines in Australia make use of the *atl-atl* and the *boomerang* instead of a bow – the introduction of flake-based assemblages seems to be quite recent (d'Errico, 2003)- although they, like all *H. sapiens*, are absolutely capable of making knots.

Finally, we are obliged to reference the most impressive pieces of archaeological record found until now concerning recursive patterns: the stones and the perforated beads found in Blombos cave, South-Africa (Henshilwood, et al., 2009; Henshilwood et al., 2002). Regarding the beads, there are obvious reasons to think that they were ornaments and that they were knotted somehow. Concerning the stones, they have been engraved with a very interesting pattern of lines, resembling a succession of rhombus. On one of the stones (item SAM-AA 8938), this patterning is much clearer than in the other (item SAM-AA 8937), with the geometric figures "better designed" so to speak, which leads one to speculate whether the worst of the pair was a first trail. In any case, the intentionality of the "artist"seems to be out of the question. Camps & Uriagereka have already pointed out that such a geometric picture could theoretically be described by a Context-sensitive Grammar, though they do not offer such a grammar.

For these reasons, it is reasonable to conceive of a scenario in which, in cognitive computational terms, Neandertals were potentially able to make knots, but never developed such an ability until they got in touch with modern humans. Nevertheless, a second scenario we can figure out is related with the possible emptiness of FLN we mentioned in the first section: Neandertals had recursion, but the divergent (both genetic and

22 For example, experiments seem to support the idea that Baboons could recognize hierarchical classifications by rank and kinship (Bergman, et al., 2003), that chimpanzees are rational maximizers in an *Ultimatum Game* (Jensen, et al., 2007), can perceive *casualty* (O'Connell & Dunbar, 2005), and understand some psychological states (Tomasello, et al., 2003), that bonobos and orangutans save tools for future use (Mulcahy & Call, 2006), or that the *endowment effect* has been detected in Capuchin monkeys (Lakshminaryanan, et al., 2008). But see (Penn et al., 2008) for a quite critical view of most assumptions made in this field.

developmental) evolution of their brains provoked the emergence of different kinds of mappings. When the process of speciation became a reality (as current genetic data seem to suggest), two different kinds of cognition had arisen. This is in tune with the following statements HCF make after quoting the third definition (cf. first section of this paper):

> "*To be precise, we suggest that a significant piece of the linguistic machinery entails recursive operations, and that these recursive operations must interface with SM and CI […]. These mappings themselves could be complex (though we do not know) because of conditions imposed by interfaces*." FHC (2005: 182) [emphasis added: LBC]

Finally, there is a third scenario supported by the strong hypothesis according to which neandertals could have lacked recursion as it is understood by linguistics, a core element for complex computations and linguistic structures. If recursion belongs first to language, as some people argue, and then has been reused in other cognitive domains, Neandertals, inasmuch lacking linguistic recursion, would have never been able to reuse it or co-opt it for making knots (as the still negative evidence suggests), nor to speak exactly like anatomically modern humans do. This hypothesis will be falsified as soon as archaeological record linkable to both *H. neanderthalensis* and recursive activity are recovered.

As a conclusion, we see that nor the current data from genetics, nor from paleoanthropological records, nor from comparative psychology still does not allow us to exclude the hypothesis according to which Neandertals might have had recursion. For this reason, it is not impossible to conceive of a Neandertal hominid executing and processing recursive patterns, but the fact is that there is still no proof of that. In order to be cautious, we still cannot assess nor include recursion in the cladogram before the split point between these two hominid species – with the exception of the starlings case, as a homoplasy case, if finally confirmed.

Conclusions

As we have seen, the evolution of language cannot be addressed from a single discipline, so others like genetics or archaeology may also have a say on this issue. There is still a lot of research needed regarding neandertal cognition, an issue that deserves more attention also by biolinguistics. Although there are reasons to think so, the available data does not allow us to exclude recursion either from *H. neanderthalensis* or from starlings' cognition. Thus, what can be called *special* in humans or in language?

Maybe the last part of the next quotation almost perfectly summarizes our own hypothesis about the role of recursion in language and in the whole cerebral architecture related to linguistic and non-linguistic activity.

> "*Something* about the faculty of language must be unique in order to explain the differences between humans and the other animals – if only the particular combination of mechanisms in FLB." (FCH, 2005: 182).

The search for the single trait that makes modern humans special seems to lead us to the conclusion that it is the specific combination of the elements which enabled the emergence of human cognition, and, maybe, as cognitive spandrels, human-specfic capacities like recursive patterning, recursive language, perception of beauty and moral sense (Nadal, et al., 2009). Further interdisciplinary research is needed in order to account for a satisfactory definition not only on the origins of recursion, but also about its autapomorphic character in *H.sapiens* and its biological nature.

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