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NP recursion over time: Evidence from Indo-European

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NP RECURSION OVER TIME: EVIDENCE FROM INDO-EUROPEAN

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Some languages constrain the recursive embedding of NPs to some specific morphosyntactic types, allowing it, for example, only with genitives but not with bare juxtaposition. In Indo-European, every type of NP embedding—genitives, adjectivizers, adpositions, head marking, or juxtaposition—is unavailable for syntactic recursion in at least one attested language. In addition, attested pathways of change show that NP types that allow recursion can emerge and disappear in less than 1,000 years. This wide-ranging synchronic diversity and its high diachronic dynamics raise the possibility that at many hypothetical times in the history of the family recursive NP embedding could have been lost for all types simultaneously, parallel to what has occasionally been observed elsewhere (Everett 2005, Evans & Levinson 2009).

Performing Bayesian phylogenetic analyses on a sample of fifty-five languages from all branches of Indo-European, we show, however, that it is extremely unlikely for such a complete loss to ever have occurred. When one or more morphosyntactic types become unavailable for syntactic recursion in an NP, an unconstrained alternative type is very likely to develop in the same language. This suggests that, while diachronic pathways away from NP recursion clearly exist, there is a tendency—perhaps a universal one—to maintain or develop syntactic recursion in NPs. A likely explanation for this evolutionary bias is that recursively embedded phrases are not just an option that languages have (Fitch et al. 2005), but they are in fact preferred by our processing system.*

Keywords: NP structures, syntactic recursion, reconstruction, Bayesian phylogenetic model, stochastic character mapping, evolutionary bias, universals

1. Introduction. It has often been noted that languages vary in the extent to which they allow syntactic recursion, that is, the embedding of a phrase of some type within another phrase of the same type, such as [$_{\text{NP}}$ [$_{\text{NP}}$ *my mother*]*'s book*] (e.g. Givón 1979, Mithun 1984, 2010, Everett 2005, Heine & Kuteva 2007, Evans & Levinson 2009, Karlsson 2010, Pullum & Scholz 2010, Viti 2015). For example, Russian allows recursive embedding of NPs if they are marked with the genitive but not if they are constructed with an adjectivizer (an affix that lets an embedded NP behave like an adjective morphosyntactically).[1]

(1) Russian
a. kniga mam-y (Ivan-a)
book(F) mother(F)-GEN.SG Ivan(M)-GEN.SG
'(Ivan's) mother's book'

*Author contributions: Data analysis: MW (lead), SA, JN, PW, BB; theoretical background: BB; phylogenetic analysis: BB; research design: PW, BB; write-up: MW, SA, JN, PW, BB. Corresponding authors: MW (manuel.widmer@uzh.ch) and BB (balthasar.bickel@uzh.ch). Acknowledgments: This research was supported by a grant from the Dean's Office, Philosophical Faculty, University of Zurich. We are grateful to the many colleagues who advised us on data in the online supporting materials, and to the associate editor and the referees for helpful comments.

[1] Most of the abbreviations in glosses are the standard ones from the Leipzig glossing rules (http://www.eva.mpg.de/lingua/resources/glossing-rules.php). Additional abbreviations are: ADJZ: adjectivizer, AI: ablative-instrumental, CO: common (gender in Hittite), DL: dative-locative, EZ: ezāfe marker, IMPF: imperfect, N: noun (head), N-H: head-marked NP, NP-A: adjectivizer-marked NP, NP-G: genitive-marked NP, NP-P: adposition-marked NP, NP-Ø: NP embedded by juxtaposition, NT: neuter, PTCL: particle.

b. (*Ivan-ov-a/Ivan-a) mam-in-a kniga
Ivan(M)-ADJZ-SG.F/Ivan(M)-GEN.SG mother(F)-ADJZ-SG.F book(F)
'(Ivan's) mother's book'

Expansion by a second NP *Ivanova* or *Ivana* in 1b is not blocked by a universal principle that shields adjectivized nouns from further modification, that is, by some simple, surface-oriented version of a lexical integrity principle (see Ackerman et al. 2011 for discussion): other languages with adjectivizing morphology—indeed, languages with morphology cognate with that in 1b—do allow recursive expansion with this kind of NP. This is the case, for example, in Upper Sorbian (Lötzsch 1965, Corbett 1987).

(2) Upper Sorbian
přez Mar-in-eje maćer-n-u smjerć
through Marja(F)-ADJZ-ACC.SG.F mother(F)-ADJZ-ACC.SG.F death(F).ACC.SG
'through Marja's mother's death'

Thus, the possibility of syntactic recursion is a parameter of variation that is independent of the specific morphological means by which the embedding relation is signaled. Also, recursion can be blocked with specific types of phrases, as in Russian, or it can be blocked across all phrase types, as has been found in the Amazonian language Pirahã (Everett 2005, Futrell et al. 2016).

The source of such variation is most likely diachronic: some structures evolved so as to freely allow syntactic recursion, for example, by expanding the usage scope of a construction to any kind of attributive relation. Other structures evolved so as to block recursion, for example, by becoming unproductive (e.g. unavailable for many nouns or restricted to two-member expressions) or by developing new dependency requirements (e.g. requiring an independent head as host). A survey of the literature suggests that unconstrained recursion (as in 1a and 2) is far more widespread in the world's languages than constrained recursion (as in 1b or generally in Pirahã). This suggests that languages in general prefer the evolution of structures that allow recursion over the evolution of structures that ban recursion. That is, there is an evolutionary bias that favors what we speak of generically as MAINTENANCE of recursion, whether through INNOVATION of a new recursive NP type, EXPANSION of the range of recursion of an existing type, or RETENTION of an existing alternative recursive type.

Here we test this hypothesis for one specific type of phrase, NPs, in the history of one specific family, Indo-European. Indo-European NPs provide an ideal test case for three reasons. First, Indo-European languages are very diverse with regard to their NP structures, which suggests that NP structures are highly dynamic and that there have been many different diachronic trials in their evolution. Second, the history of the language family is relatively well known, so that the evolution of syntactic structures can be explored both qualitatively and quantitatively. Third, individual Indo-European languages constrain recursion in different types of NPs, so that the possibilities of recursion are independent of the specific morphosyntactic form of the NP and independent of any constraints that might attach to this form.

In what follows we first introduce and elaborate the hypothesis, grounding it in theories on the relevance of recursion and hierarchical structure in syntax (§2). We then perform a test of the hypothesis (§3), using both qualitative and quantitative methods. In the final section (§4) we frame our findings in a more global perspective and suggest further research.

2. THEORETICAL BACKGROUND.

2.1. CLEARING THE TERMINOLOGICAL THICKETS. There are few terms in linguistics that have created more confusion than the term 'recursion'. The key distinction is between (i) syntactic recursion in the sense of self-similar embedding, for example, of an NP inside an NP, and (ii) the notion of recursion in mathematics (Fitch 2010). Syntactic recursion relies on, but does not reduce to, mathematical recursion. Recursion in the mathematical sense is a necessary property of any intensionally specified finite system that can generate infinite sets (e.g. the natural numbers) by inductive definition (Fitch 2010, Watamull et al. 2014). This property may or may not characterize human grammar, or individual parts thereof, and it may or may not have evolved specifically for human language (see e.g. Hauser et al. 2002, Pinker & Jackendoff 2005, Perfors et al. 2010, Martins et al. 2016 for various positions here).

Syntactic recursion, as we understand it here, is present whenever a grammar can freely embed a phrase XP inside the same phrase XP, and—unlike recursion in the general mathematical sense—also assigns a structure of embedding with categories and relations that are repeated at each level to the resulting expression: an XP_n is recursively embedded into an XP_{n+1} iff the distributional properties of XP_n and the relationship between XP_n and XP_{n+1} are the same for all *n*, and there is no grammatical restriction on the value of *n*.[2] Not all structures are built this way. For example, combining a subject and a verb does not involve syntactic recursion in this sense because there is no identity of XPs across levels. Nor does example 1b result from syntactic recursion: it is nonrecursive because there is an arbitrary grammatical constraint that sets $n = 1$.

These statements are about what Martins (2012) calls the 'distinctive signature' of recursion, based on observable ('surface') category distributions (an XP is embedded in an XP and not in a YP), observable semantic relations (an embedded XP modifies an embedded XP, which in turn modifies a head), and observable constraints on levels (unlimited *n*). As such, our definition of syntactic recursion (like that of, for example, Futrell et al. 2016) is fully orthogonal to the question of how one wishes to formally model syntax. It is always possible to model any syntactic structure with a recursive operation in the broader mathematical sense, combined with some category-labeling mechanism (e.g. Everaert et al. 2015). Under such a conception of syntax, our notion of syntactic recursion would need to be defined in terms of label distributions and possible values of *n*, but the empirical issues (the ungrammaticality of 1b vs. the grammaticality of 2) remain the same.

Also, our notion of syntactic recursion is independent of the various kinds of markers that grammars employ when embedding phrases, such as genitives, adjectivizers, linkers, adpositions, and complementizers. Some of these come with additional category properties: for example, they assign an adjective or adposition property to the embedded NP: $[_{NP}\ [_{AP}$ NP-ADJZ] N] or $[_{NP}\ [_{PP}$ NP P] N]. However, to the extent that the embedded NP itself keeps the same distributional property as the higher NP, this still counts as recursion in our sense. As was illustrated in the discussion of the introductory examples in 1 and 2, the presence of such intervening elements, or indeed any other signal or marker of the embedding relation, is in principle independent of whether a phrase can be recursively elaborated. But we take up this issue again in §3 below.

A notion that is sometimes taken as indicative of recursion (in either the syntactic or the mathematical sense) is hierarchical structure and embedding relations, but this is misleading. A structure is hierarchical if it satisfies the definition of an undirected acyclic graph with a distinct root, also known as a rooted tree (Fitch 2014). Grammars that generate hierarchical structure may or may not include recursion (Fitch 2010, Per-

[2] Compare this with a recursive definition in mathematics, for example, the common definition of the factorial function as $n! = n(n-1)!$ for $n > 0$, and $n! = 1$ for $n = 0$. This function does not assign any categories and relations, and it terminates in a simple number, not a phrase structure.

fors et al. 2010, Tiede & Stout 2010, Fitch & Friederici 2012, Martins 2012, Martins et al. 2016). For example, a hierarchical structure may have limited depth, as is the case in our initial observation 1b. More generally, hierarchical structures can be stipulated by declaring one-off 'embedding' relations, for example, in the form of fixed constructional schemas or templates. What syntactic recursion yields beyond such templates is unlimited expansion in embedding depths, and, equally important, recursion guarantees identity of categories across levels: while both the rule pair 'embed B in A' and 'embed C in B' and the single recursive rule 'embed α in α (with α =: {A,B,C})' can generate the hierarchical structure [A[B[C]]], only the recursive rule assigns the same category label α to all three constituents (Martins 2012).

2.2. Recursion as a processing preference. Despite this definitional independence, we contend that there is a natural link between the faculties for mathematical recursion and hierarchical structure on the one hand, and the presence of syntactic recursion in languages on the other. This link is established via the role of processing in language change. In brief, we propose that grammars with syntactic recursion are preferred (but not required) by the processing system, and that this preference establishes an evolutionary bias so that grammars with syntactic recursion are more likely to develop and persist over time than grammars without syntactic recursion. We elaborate the motivation for this proposal below, but we first clarify how it differs from other proposals.

As noted above, a prominent alternative proposal for linking the mathematical and the syntactic concepts of recursion is to build recursion in the mathematical sense directly into the very foundation of syntax (e.g. Hauser et al. 2002). This is usually motivated by assuming that syntactic structure must allow infinite—and thus recursively defined—counting of embedding levels in unbounded dependencies (Chomsky 1957, 1975 [1955]).[3]

Such a model of grammar entails that unconstrained syntactic recursion (in the sense defined above) is necessarily a universal option for human language (Fitch et al. 2005, Watamull et al. 2014). But the model makes no prediction on the distribution of syntactic recursion over time, over space, or over individual phrase types (nor on the use of recursion in discourse, for that matter). One would expect random developments here that are only tied to the vagaries of lexical evolution, such as the various ways in which complementizers or genitives come and go. By contrast, our proposal predicts constraints on these developments, favoring phrase types that allow syntactic recursion over those that do not.

The motivation for our proposal is as follows. It has long been proposed and experimentally substantiated that the human processing system not only has a faculty for hierarchical structure, but the system actually prefers hierarchical over serial structures when confronted with a string of symbols (e.g. Miller 1967, Pallier et al. 2011, Fitch 2014, Christiansen & Chater 2016, Ding et al. 2016). In language, this human dendrophilia (as Fitch 2014 terms it) is most efficiently satisfied by the use of syntactic recursion. In other words, increased use of syntactic recursion in grammar makes the processing of the favored type of structure, viz. hierarchical structure, more efficient. Evidence for this claim comes from two observations. First, syntactic recursion makes it straightforward

[3] The alternative, which often goes unnoticed, is to dispute the claim that infinite counting in syntax is necessary for linguistic creativity (Pullum & Scholz 2010, Pullum 2013) and/or for sufficient information-carrying capacity (Kornai 2014). This then suggests models of grammar that stipulate constraints on structures without presupposing anything about the finiteness of the set of structures or expressions in a language.

to assign the same properties to different syntactic units: rather than stipulating by an extra rule that the higher NP in [$_{NP}$ [$_{NP}$ *my uncle*]*'s house*] has the same distributional ('N') properties as the lower NP, a recursive grammar provides this information about self-similarity for free, and indeed guarantees it (Martins 2012). Second, some amount of syntactic recursion seems to lead to the computationally best tradeoff between formal grammar complexity and data coverage in language acquisition (Perfors et al. 2010). Taken together, these two observations suggest that syntactic recursion makes a grammar computationally simpler, and it is likely that the processing system generally prefers simpler systems (e.g. Bornkessel-Schlesewsky & Schlesewsky 2009).[4]

Independently of this, there is good reason to assume that the human brain indeed prefers to apply its general faculty for recursion when processing syntax. This means that syntactic recursion is likely to be preferred not only for its specific computational benefits when processing hierarchies, but also because of a much broader and more general bias. Initial support for this comes from the sheer ubiquity of recursion outside syntax: for example, in visual cognition (Pinker & Jackendoff 2005, Martins et al. 2016), where recursion is a key mechanism in pattern detection; in spatial navigation or kinship calculation, where recursion allows predicting the properties of unseen entities (as the same or as bearing the same relation; Martins 2012); and in theory-of-mind cognition, where recursion enables us to think from the perspective of another person, place, or time (Corballis 2011), as well as enabling mental-state attribution (Grice 1975, Tomasello 2008). In all of these areas, it seems that recursion brings about massive cognitive benefits with limited resource pressure. Initial evidence for such benefits has recently been established through fMRI studies of visual processing (Fischmeister et al. 2016). These findings make it likely that recursion is also put to extensive use in other areas of higher cognition, such as the construction of syntactic phrases.

Given these observations, we expect the following hypothesis to be true.

(3) Hypothesis: All else being equal, for any kind of syntactic phrase (e.g. NPs), the human processing system prefers a grammar that includes recursion as a structure-building operation over a grammar that does not include recursion, as detectable through the distinctive signatures of syntactic recursion (i.e. identity of categories and relations across embedding levels and no grammatical constraint on the number of embedding levels).

As in other such cases, a processing-based hypothesis like that in 3 makes a prediction about the probabilities with which syntactic structures evolve in language change (e.g. Hawkins 1994, 2014, Croft 2003, Blevins 2004, Christiansen & Chater 2008, Kemmerer 2012, Bickel 2015, Bickel et al. 2015, McDaniel et al. 2015): at any point in time, given the choice between a nonrecursive, limited-depth grammar of, say, NP construction and an unconstrained, recursive grammar, the processing system will (according to the hypothesis) tend to apply the recursive one. In many cases, there is no choice (i.e. not all else is equal): only one type of NP construction may be available for a given

[4] A referee asks why one could not simply claim that expressing ideas like 'Ivan's mother's book' would be complicated without syntactic recursion. The problem is that, when used in some real context, there are many ways in which one can easily express such ideas without recursive NP embedding, for example: *Let's read this book. It was written by Ivan's mother*. Distributing information in this way is very common in actual discourse and is not particularly complicated—indeed, probably even simpler. See Pullum & Scholz 2010 and Kornai 2014 for the general point that a lack of syntactic recursion does not in any way interfere with expressive power.

meaning, for many different reasons (e.g. it might not be possible to express possession with adjectivally marked NP embedding in a given language). But to the extent that the choice arises (e.g. *American territory* vs. *territory of America*) and there is a contrast in recursiveness, the system will favor the one allowing recursion. Given enough such occasions over time, and absent any sociolinguistic constraints, recursive grammars are then expected to gain ground. Such an evolutionary scenario is entirely parallel to established theories that predict, for example, the phonologization of final devoicing because of its energy-saving aspects (Hyman 1976, Lindblom et al. 1995, Boersma 1998, Blevins 2004): languages tend to develop and maintain final devoicing unless the change is blocked by some other process (e.g. sociolinguistic pressure against language change, contact effects favoring another structure, etc.).

Given this, the hypothesis in 3 predicts for any surveyed lineage that, whenever a language develops constraints on recursion in some phrase, the possibility of recursion is likely to be restored over time, or an unconstrained alternative type of the same phrase is likely to expand its range of use, that is, apply to more contexts and become the preferred type over time. For example, recursion of NPs with genitives might become blocked for some reason: genitives might become strongly associated in frequency with two-word idioms, or they may become unavailable for many nouns on phonological grounds, or the entire construction loses popularity in the wake of language contact, and so on. If any such development takes place, we predict a high probability that the original type will be restored (e.g. by developing a new genitive that allows recursion) or that an alternative type, for example, a type involving adjectival morphology, will be expanded in its use and become fully available for recursion. As a result of this, we expect that for each phrase (e.g. NPs or clauses), it is very likely that there will be at least one type that allows syntactic recursion at any given time.

The hypothesis will be falsified if recursion, when lost from some phrase type, is not restored either by renewing the original pattern or by extending another. In that case, the distribution of syntactic recursion will result from a pure-chance process, perhaps coupled with factors from language contact or other local patterns, but without any systematic, universal bias. As a result, many languages are expected to develop in the way claimed for Pirahã (Everett 2005) and have no phrase type that freely allows recursion.

For the hypothesis to be testable, a variety of different phrase types needs to be able to develop, and there needs to be at least some overlap in what these types can express—that is, the types should not be completely functionally distinct. If the types are fully distinct, the processing system cannot freely choose between them, and the system could not even start to favor one or the other. In our case study below, we therefore first establish that a range of different types developed, and that each of these types became the dominant or default structure for recursion in at least one language. This is only possible if the types share enough functional ground.

Another requirement for testing the hypothesis is diachronies that are sufficiently unstable; that is, structures must come and go within known or at least reconstructable time at least once, and ideally many times.[5] Only then can we sample transitions and assess whether overall these transitions lead to syntactic recursion significantly more often than not. In our case study, we therefore first establish that each type is sufficiently dynamic to provide a test case.

[5] The technically minimal requirement is that the recursive and nonrecursive states are strongly connected, that is, that no transition between these two states ever has the probability of exactly 1 or 0 (Greenberg 1995, Maslova 2000). But for sampling purposes, transition probabilities close to 0 are already problematic.

For a full test of the hypothesis, we need an extensive worldwide sample of the (reconstructed) diachrony of various phrases, so that we can compare the number of diachronies in line with our hypothesis and the number of diachronies in conflict with our hypothesis. No database of such breadth and scope is available at present. Instead, we focus on one phrase and one family: NPs in Indo-European. Here we can survey a substantial range of diachronies—that is, we can test the hypothesis against a relatively large sample of individual diachronic transitions and thereby gain initial evidence for or against the hypothesis.

3. NPS IN INDO-EUROPEAN AS A TEST CASE. As noted above, there are two preconditions for our hypothesis to show any effects in a language family: first, several different morphosyntactic types of NPs (i.e. different ways of marking or establishing the embedding of an NP in an NP) need to be available and overlap in their functions. This makes it possible for speakers to choose one type and use it for recursion in at least some contexts. We therefore first (§3.1) survey the range of morphosyntactic types that is attested across Indo-European languages and show that each type has become the dominant choice for NP recursion in at least one language.

This proves that there is no type that is intrinsically constrained to specific functions and could never be chosen as an alternative. We show this in detail in §3.2, providing additional evidence for functional overlap between the types in the course of their history. The second precondition is that the range of types must be sufficiently dynamic over time. This enables us to trace transitions between types and test our prediction that there are significantly more transitions that make NP recursion available than transitions that make NP recursion unavailable. We demonstrate this in §3.3 through attested or reconstructable transitions. Once this is established, we summarize the distribution of the types that are vs. are not available for recursion and report evolutionary biases based on Bayesian phylogenetic analyses (§3.4).

3.1. A SURVEY OF NP TYPES. Across the family, there are at least five morphosyntactic types for how the embedding of an NP in an NP is marked or established. All five types are prominent means for syntactic recursion in one or more branches: genitives, adjectivizers, head marking, adpositions, and juxtaposition. Each of these types has become the dominant or a particularly popular structure in at least one daughter language. We analyze an NP type as being available for syntactic recursion if the type can indicate the embedding of an NP that is in turn modified by another NP. For example, the genitive type is available for recursion if genitives can mark an NP that contains another NP (of any type). This is true of the genitive *mamy* 'mother's' in Russian (1a) and of English *'s*-genitives like *mother's* (cf. *John's mother's book*, *my mother's book*, etc.), but not of adjectivizer-marked expressions like *mamina* 'mother's' in Russian (1b).

In the following we briefly survey the five types that are prominent in Indo-European. For detailed philological discussion of all data and justification of our analyses, see Supporting Material 1.[6]

GENITIVES. We define genitives as dependent markers that behave as case markers, phonologically hosted by stems or entire phrases (e.g. in the case of English *'s*). Unlike adpositions, genitives are not independent words with a distinct part-of-speech property and argument structure, and as a result they do not assign case. Unlike adjectivizers,

[6] All supporting materials referenced here and throughout the article can be accessed at http://muse.jhu.edu/resolve/28.

genitives do not add an adjectival property to the embedded NP and therefore do not, for example, show any agreement. We notate embedding by means of genitives as [[NP-G] N]. Genitives are the only fully productive strategy for recursive NP embedding in Hittite, a long-extinct language of the Anatolian branch.[7]

(4) Hittite
^{D}IŠTAR-aš lūli-aš KÁ.GAL-az
Ishtar(CO)-GEN pond(CO)-GEN door-ABL
[[[NP-G] NP-G] N]
'from the door of Ishtar's pond' (KBo XVI 49 I 6; Yoshida 1987:19)

ADJECTIVIZERS. Adjectivizers embed an NP by adding a morphosyntactic adjective property, such as agreement, to it. Often this is a lexically self-contained process that can only apply to noun stems, but, as we noted in the introductory example 2 from Upper Sorbian, adjectivization can be used for embedding full NPs as well, that is, NPs with their own NP subconstituents. We notate adjectivization as [[NP-A] N]. This pattern had become the only fully productive way of NP embedding in a sister language of Hittite, Luwian. The following examples are from Hieroglyphic Luwian (henceforth 'H. Luwian'), attested through inscriptions involving logograms.[8]

(5) H. Luwian
a. Tuwana-wanni-s(URBS) |REXti-s
Tuwana(CO)-ADJZ-NOM.SG.CO king(CO)-NOM.SG
[[NP-A] N]
'the king of Tuwana (city)' (BOR §1; Bauer 2014:151)
b. [a]wa=ta |z[ati] ámi$_i$ áláyaza$_i$-ss-an
PTCL=PTCL this.DL.SG.NT 1SG.POSS.DL.NT Arrayazza(CO)-ADJZ-DL.SG
[[NP-A] [NP-A]
HÁ+LI-ass-an SERVUSla-ya$_i$ STATUArut-i
Hattusili(CO)-ADJZ-DL.SG servant(CO)-ADJZ.DL.SG statue(NT)-DL.SG
[[NP-A] NP-A] N]
OVIS(ANIMAL)-ti PRAEi (*69)sasa-tu
sheep(CO)-AI.SG ADV present-3PL.IMP
'Let them present(?) the statue of me, of Arrayazza, of the servant of Hattusili, with a sheep.' (MALPINAR §5; Bauer 2014:148)

The basic construction is shown in 5a. The sentence in 5b contains an NP with recursive embedding: the head noun STATUA*ruti* 'statue' is modified by the conjoined adjectivizer-marked *áláyazassa* 'of Arrayazza' and SERVUS*laya* 'of the servant' (and both are in apposition to the initial possessive pronoun *ámi*). The NP SERVUS*laya* 'of the servant' is in turn recursively modified by another possessive adjective NP *HÁ+LI-assa* 'of Hattusili'.

[7] The Hittite writing system is a mixture of logograms and phonetic forms. Words can be written by either a logogram or a phonetic form, or as a logogram with a phonetic component. Logograms may also stand before phonetic words as a semantic marker dubbed 'determinative'. By convention, logograms are rendered in capitals if they are Sumerian and in italic capitals if they are Akkadian. Determinatives are rendered as superscripts.

[8] Orthographic conventions are similar to those for Hittite, except that logograms are conventionally rendered as their capitalized Latin counterpart or their capitalized Anatolian spelling, if known. Determinatives are put in brackets. Special symbols include '|' for word divider and square brackets for broken signs (Bauer 2014:xiii).

A variant of adjectivizers assigns case to the embedded NP. This variant has become the dominant construction in Hindi and many other Indo-Aryan languages. The embedded NP is marked by a clitic adjectivizer =*k*-, which takes a further suffix agreeing in case, gender, and number with the head noun and which additionally assigns oblique case to its host (although case is visible only in some noun classes).

(6) Hindi

Khannā=k-ī	bahin=k-e		
Khanna(m)=adjz-obl.sg.f	sister(f).obl.sg=adjz-obl.sg.m		
[[[[NP-A]	NP-A]		
	kutt-e=k-ā		nām
	dog(m)-obl.sg=adjz-nom.sg.m		name(m).nom.sg
	NP-A]		N]

‘Khanna’s sister’s dog’s name’ (Snell & Weightman 2003:66)

A similar construction is attested in Albanian, where an adjectivizing ‘particle of concord’ assigns dative case to its host (Newmark et al. 1982:159–62). We do not analyze the Albanian and Hindi constructions as a type of their own, distinct from other adjectivizers. The key feature that marks the embedding relation is that the adjectivizer (=*k*- in Hindi) assigns a morphosyntactic adjective property to the embedded NP, thereby requiring agreement. The oblique case is only a side effect that results from the etymology of the adjectivizer.

Adjectivizers are very frequent in Indo-European with embedded pronouns. Instead of genitives one often finds special possessive pronouns that agree in case, number, and gender with their head (e.g. German *sein-en Brüder-n* ‘his-dat.pl.m brother(m)-dat.pl’). However, when this strategy is limited to pronouns (as it is, for example, in German), it is functionally specialized for this and does not offer the open choice for NP embedding that our hypothesis seeks. We therefore exclude possessive pronouns from our survey.

Head marking. In this type, the embedding relation is marked on the head, unlike in all other types discussed so far. We notate this as [[NP] N-H]. The type is prominent in Persian, for example, where the relevant marker is known as the ‘ezāfe’ marker.

(7) Persian

ketāb-e	pedar-e	Hasan
book-ez	father-ez	Hasan
[N-H	[N-H	[NP]]]

‘the book of Hasan’s father’ (Lazard 1992:67)

The head-marking type also dominates several Germanic languages, where it involves possessive pronouns or particles derived from them. An example is Afrikaans.

(8) Afrikaans

ons	bur-e	se	vriend-e	se	seun
our	neighbor-pl	poss	friend-pl	poss	son
[[[NP	]	N-H	]	N-H	]

‘our neighbors’ friends’ son’ (Donaldson 1993:98)

A variant of this, popular for example in Swiss German, involves additional dative case marking on the dependent. This results in double marking and is illustrated by the dative case on the dependent NPs (*er Anna* ‘Anna’ and *irem Brueder* ‘her brother’) in the following example (for a parallel development in Ossetic, see §12.5 in Supporting Material 1).

(9) Swiss German (Bernese dialect)

er	Anna	ir-em	Brueder	si-s	Huus
ART.DAT.SG.F	Anna(F)	3SG.F.POSS-DAT.SG.M	brother(M)	3SG.M.POSS-NOM.SG.NT	house(NT)
[[[NP	]	N-H	]	N-H	]

‘Anna’s brother’s house’

We do not distinguish this type of double marking from simple head marking (Nichols 1992, Nichols & Bickel 2005) for current purposes. What sets the Swiss German construction apart from the other types is the appearance of a head marker. The dependent-marking component by means of case continues a standard pattern.

ADPOSITIONS. In Indo-European languages, adpositions are distinct syntactic words that are relatively independent of their host. As such, they typically govern case and can sometimes be stranded. English *of* is a prominent example, and it is one of the dominant strategies for recursive embedding in the language. We notate adposition structures as [[NP-P] N]. Apart from English and other Germanic languages, the pattern has also become the strategy of choice in several Romance languages, for example, in Spanish.

(10) Spanish

el	perro	de-l	padre	de	mi	amigo
ART.SG.M	dog(M)	of-ART.SG.M	father(M)	of	1SG.GEN	friend(M)
[	N	[NP-P		[NP-P	[NP-G]	]]]

‘the dog of my friend’s father’ (Martha Mariani, p.c.)

As case survives only in pronouns in Spanish, the fact that *de* is an adposition and not a phrasal case affix is evident only when *de* occurs in combination with pronouns (cf. *Hablan de mí* ‘They speak of me’, where the first-person singular pronoun stands in a ‘prepositional case’, which only occurs in combination with adpositions).

JUXTAPOSITION. Another frequent type of NP is formed by endocentric (also known as determinative) juxtaposition, without any dedicated marking. Juxtaposition is traditionally distinguished from compounding, but this distinction is most often only made on the basis of phonological criteria and as such is independent of the syntactic structure, so we group the two together. Another distinction is sometimes made between two morphosyntactic types: juxtaposition of a full-fledged NP (which, for example, admits further morphology, articles, and other modifiers) and a head noun vs. compounding as a process of stringing together stems into words. While important on its own, the distinction is immaterial for our purposes as long as the resulting string is built up recursively: a modifying N or NP modifies an N or NP that again modifies an N or NP. We notate these structures here generally as [[NP-Ø] N], assuming phrasal analyses throughout: $[_{NP} [_{NP} [_{NP}$ N] N] N]. Alternatively, one could analyze these structures as involving stems and incorporation (or movement) of each embedded element into its next higher head [[[N-]N-]N] (where the hyphen indicates incorporation). As long as the incorporation analysis allows for recursive embedding and there is no marking of the embedding relation, the two analyses are equivalent for our purposes.

Juxtaposition is highly popular in Germanic—for example, German or English.

(11) German

Auto-	reifen-	wechsel	
car(NT)	tire(M)	replacement(M)	
[[[NP-Ø]	NP-Ø]	N	]

‘car tire replacement’

Where it occurs, juxtaposition tends to favor embedding of the same unmarked type (here the complex NP [[*Auto*-]*reifen*]), but several languages also allow recursion with other types as well. In Vedic Sanskrit, for example, a juxtaposition member can consist of an NP with an embedded genitive-marked NP (a pattern also observed in Pāli and Avestan; cf. §§11.7 and 12.1 in Supporting Material 1, respectively).

(12) Vedic Sanskrit

árvato	māṃsa-	bhikṣā́m
horse(F).GEN.SG	meat(NT)-	request(F).ACC.SG
[[[NP-G]	NP-Ø]	N]

‘the request for the meat of the steed (sc. the aforementioned horse which is being cooked during the horse sacrifice)’

(Rig Veda 1.162.12c; Wackernagel 1905:31)

The most flexible version of juxtaposition is one where full-fledged NPs can be recursively stacked. This is the type that is popular in several modern Celtic languages, such as Modern Breton.

(13) Modern Breton

pneuioù	marc’h-houarn	glas	ma	mignon	gwellañ
tire(M).PL	horse(M)-iron(M)	blue	1SG.GEN	friend(M)	best
[N	[NP-Ø		[[NP-G]	NP-Ø	]]]

‘the tires of the blue bicycle of my best friend’ (Herve Le Bihan, p.c.)

Note that for juxtaposition to be fully comparable to the other NP types discussed here, it needs to involve recursion in the sense defined above: an embedded NP is embedded into another NP, which in turn is embedded into another NP. The literature on juxtaposition, especially when focusing on ‘compounding’, often adopts a broader notion of recursion that applies to all cases where compounds are members of compounds, as when, for example, a noun modifies a compound noun as a whole (e.g. [*student* [*film award*]]). A recursive version of this in our sense requires that the embedded noun *film* or *student* is modified by another modifier noun, for example, [[[*action*] *film*]] *award*] or [[[*bachelor*] *student*] [*film award*]].

Also, we exclude from our purview exocentric juxtaposition (bahuvrīhi compounds, as in Vedic Sanskrit *marútas rúkma-vakṣasas* (Marut.NOM.PL decoration-chest.ADJZ.NOM.PL) ‘Maruts (a class of gods) with decorations on their breasts’): in most cases it is the embedded juxtaposition as a whole that assumes the function of a modifier (e.g. [*marútas* [*rúkma-vakṣasas*]]). Furthermore, these juxtapositions draw on a heterogeneous set of [X N] and [X V] constructions that admit a broad variety of incorporated modifiers, very often adverb-like in function (cf. Vedic Sanskrit *raghu-yā́-man-* (rapid-go-NMLZ-) ‘with a rapid course’, English *white-washed wall*, *cross-sectional study*).

3.2. FUNCTIONAL OVERLAP. The survey in the previous section shows that each of the five NP types is the dominant or even the sole type that is available for recursion in at least one daughter language. This suggests that there is no family-wide limitation that intrinsically blocks any of the types from taking over the semantic domain that is covered by another type. For such takeovers to be possible in history, the functions of the types must overlap at least to some extent.

For some specific pairs of types, functional overlap can even be directly observed in synchronic data or in well-established reconstructions. The overlap between genitives and adpositions, for example, can be observed in synchronic data from several Germanic languages. English is a case in point and has alternations like *the office of our administrator* and *our administrator’s office*, which differ only very minimally in meaning. Similarly, the overlap between genitives and juxtaposition is well established in several Celtic languages. The two types alternate freely in Middle Breton, for example.

(14) Middle Breton (de la Haye & Gueguen 2002)

a. oa cousquet en Sacristery a Lantreguer
be.IMPF.3SG sleep.PTCP in sacristy(F) GEN Lantreguer
'he was sleeping in the sacristy of Lantreguer' (79.9–11)

b. cousque en Sacristery Lantreguer
sleep.IMPF.3SG in sacristy(F) Lantreguer
'he used to sleep in the sacristy of Lantreguer' (21.4–5)

The functional overlap between genitives and adjectivizers reconstructs for several nodes in the tree. One case is Anatolian, where in one daughter language (Hittite), the inherited Proto-Indo-European genitive (*-*s* and its declension-class allomorphs; Fortson 2010:126) took over the entire functional domain of NPs, while in another daughter language (H. Luwian), the inherited Proto-Indo-European adjectivizer (*-(i)yo*; Fortson 2010:134f.) took over the same domain. This presupposes that the two types overlapped in this domain. A parallel case is Indo-Aryan, where some adjectivizers and genitives reconstruct to one and the same etymon: the Hindi adjectivizer =*k*-, illustrated in 6 above, derives from the same participial form of *kr̥*- 'do' as the Nepali genitive *-ko*, illustrated in 20 below. The etymology is well established (Masica 1991:243), and we briefly present evidence for it in §3.3 below.

The overlap between genitives and adjectivizers is likely to reconstruct even to the Proto-Indo-European level since *-*s*-genitives and *-(i)yo*-adjectivizers seem to have been treated as equivalent in at least some contexts. Evidence for this comes from the *o*-stem genitive allomorph *-*syo* and the adjectivizer suffixes Tocharian *-ṣṣe-* and Luwian/Hittite *-assa-*. If Anatolian is any indication of an inherited *o*-stem genitive *-*s* (e.g. Hittite *atta-s* NOM/GEN 'father'/'of the father'), the ending *-*syo*, which is attested in Armenian, Italic, Indo-Iranian, and Greek, is likely to represent a combination of this genitive *-*s* with *-*(i)yo*, which presumably had a broad attributive function (Fortson 2010:134). Also, both the Tocharian B *-ṣṣe-* and the Luwian/Hittite *-*assa-* adjectivizer can be traced back to *-*syo-*. The only difference between these adjectivizers and the genitive in *-*syo* is that the adjectivizer agrees with the head of the NP, whereas the genitive does not. All of this suggests an intimate functional and formal relation between the *o*-stem genitives in *-*s* and *-*syo*, the adjectivizer *-*(i)yo*, and also the linking particle/relative pronoun **yo*, at least at some diachronic stage.

Finally, the functional overlap between adjectivizers and head markers is reconstructable in Iranian. Here, the Persian head marker (ezāfe) *-e* that was illustrated in 7 above derives from the same etymon that gave rise to an adjectivizer in another daughter language, Northern Kurdish (Haig 2011:367).

(15) Northern Kurdish
Tu kijan hesp-î di-bîn-î? — Yê Soro.
2SG which horse(M)-OBL IND-see.PRS-2SG EZ.M Soro(M)
'Which horse did you see?' — 'Soro's'

The marker *yê* is cognate with the Persian ezāfe, but *yê* behaves like an adjectivizer: it agrees with the head noun (here in masculine gender), and it is a co-constituent of the dependent, as evidenced by the fact that [*yê Soro*] constitutes a fully independent NP. In Persian, an answer to 'which horse' cannot be **e Soro*, but rather has to be *māl-e Soro*. This is because *-e* is a head marker and not an adjectivizer and, accordingly, always has to be attached to a head constituent. In the absence of an overt head noun, the ezāfe is thus attached to the semantically unspecific head constituent *māl* 'property' instead (Windfuhr & Perry 2009:435).

A parallel overlap between adjectivizers and head markers is likely to reconstruct also at some higher node in the family, predating at least the split between Balto-Slavic and Indo-Iranian. Evidence comes from the fact that the Iranian ezāfe is partly cognate with the Balto-Slavic adjectivizing suffix *-ji/o-*. In Modern Lithuanian, the definite adjective is formed by suffixing the inflected marker *-ji-* to the fully inflected stem of the adjective as in 16a, where the adjective *ger-ą* as well as the definite marker *-jį* agree in gender, number, and case with the head of the NP. In Old Lithuanian this marker was also used as an adjectivizer. In 16b, for example, the adjectivizing *-ia*, which agrees with the head *diewa*, serves to mark the locative *danguie* 'in heaven' as being embedded in an NP.

(16) a. Modern Lithuanian
gẽr-ą-jį šùn-į
good-ACC.SG.M-DEF.ACC.SG.M dog(M)-ACC.SG
'the good dog'
b. Old Lithuanian
pon-a diew-a musu dangu-ie-ia
lord(M)-GEN.SG god(M)-GEN.SG 1PL.GEN heaven(M)-LOC.SG-ADJZ.GEN.SG.M
'of our lord, god in heaven' (Petit 2009:318)

3.3. THE DYNAMICS OF NP TYPES. None of the five types surveyed is very stable historically: for each type, we found at least one case in which it developed or declined in historical time, with attested or reconstructable stages. When specific types disappear, this is in most cases the result of morphological decay or of reanalysis. For example, a genitive decays by becoming unproductive or eroded, or adpositions are reanalyzed as new case markers. When types are innovated, this mostly results from expansion in use or again from reanalysis. For example, juxtaposition becomes more popular and unconstrained, or a pronominal element is reanalyzed as a head marker. Table 1 lists one attested or reconstructable example for each transition. We discuss each example in what follows.

TYPE	UNAVAILABLE ≻ AVAILABLE	AVAILABLE ≻ UNAVAILABLE
Genitives	Breton *a*	H. Luwian GEN ≻ constrained
Adjectivizers	Hindi *kā*	Nepali ADJZ *kā* ≻ GEN
Head markers	Young Avestan ezāfe	Ossetic ezāfe ≻ constrained
Adpositions	Middle Persian (various)	Modern Persian (reanalyzed as case)
Juxtaposition	Icelandic	Nepali

TABLE 1. Attested or reconstructed transitions between availability and nonavailability of an NP type for recursion, with one example each.

GENITIVES. Older stages of Insular Celtic have preserved the Proto-Indo-European genitive, but in Breton new genitival phrasal prefixes have developed from prepositions. The marker does not govern any case and is syntactically completely dependent on its host NP, from which it cannot be stranded.

(17) Modern Breton
ur plac'hig yaouank a-n oad a bemzek vloaz
a girl(F) young GEN-ART age(M) GEN 15 year(M)
[N [NP-G [NP-G]]]
'a young girl of the age of fifteen years' (Hemon 1976–1998:34)

The affixal status of the marker is particularly evident when it occurs with personal pronouns. In this context, *a* fused completely with a special form of the pronoun and neither can occur without the other, as in, for example, *ahan-off* (GEN-1SG) 'of me, mine'.

Loss and re-innovation of genitives is not the only option. In H. Luwian, for example, the genitive did not disappear but became limited to single-level constructions. There are attested cases of NPs containing a single embedded genitival NP, but no cases are attested with recursive embedding.

(18) H. Luwian
VITIS-si FINES-s
vineyard(NT)-GEN.SG border(CO)-NOM.SG
'the border of the vineyard' (BABYLON 1 §6; Hawkins 2000:392, Bauer 2014:143)

The H. Luwian corpus is limited in size, but it is dominated by possessive relations, often very complex ones (Bauer 2014:132), and so one would expect recursively expanded genitival NPs to show up if they were possible. What H. Luwian uses for recursive NP embedding is adjectivizers of the kind illustrated earlier by example 5.

This process of gradual reduction of genitives is frequent elsewhere in the family. When the genitive was lost in Western Europe it was typically replaced by adpositions; when it was lost in Indo-Iranian, it was typically replaced by adjectivizers (Indo-Aryan) and head-marking constructions (Iranian).

ADJECTIVIZERS. Wherever they are available for recursive embedding, adjectivizers are innovations. An example is Hindi =*k*-, which (as noted above) derives from a participle based on a root *kr̥*- 'do' (Masica 1991:243). Intermediate stages are attested (Bubenik 1998, Reinöhl 2016). Consider the following twelfth-century example where the *kr̥*-form has two possible analyses (separated by a pipe operator '|' in the interlinear gloss).

(19) a. Middle Indo-Aryan (twelfth century CE)
kesari jasu keraeṃ huṃkāraḍaeṃ
lion(M).NOM.SG REL.GEN.SG.M (do.PTCP|ADJZ).INS.SG roaring.INS.SG
muhahuṃ paḍanti tr̥nāiṃ
mouth(NT).GEN.PL fall.3PL grass(NT).NOM.PL
(Hemacandra 8.4.422; Bubenik 1998:75–76)

b. Modern Hindi translation
vah śer jis=k-ī
DEM.NOM.SG lion(M).NOM.SG REL.OBL.SG=ADJZ-OBL.SG.F
garaj-se tum-hār-e mũh-se
roar(F).OBL.SG-from 2SG-ADJZ-OBL.SG.M mouth(M).OBL.SG-from
khānā gir gayā thā
food(M).NOM.SG fall be.PST.SG.M go.PTCP.NOM.SG.M
'the lion by whose roaring grass fell from your mouth' (Reinöhl 2016)

The form *keraeṃ* is ambiguous between a literal translation as a participial form 'by whom the roaring was made/done' and a reanalysis as an adjectivizer that embeds the relative pronoun *jasu* ('whose roaring, roaring of whom'). In the Hindi translation (19b) the reanalysis is completed.

In several Indo-Aryan languages, adjectivization became unavailable again because the *k*-markers were further reanalyzed as plain genitives, shedding all agreement, government, or other adjective properties. The transition is still ongoing at present in Nepali, where more innovative dialects (especially in eastern Nepal, with many Tibeto-Burman L2-speakers) have completely lost the agreement options (see §10.7 in Supporting Material 1).

(20) Nepali
us-ko   sāthi-ko   didi-ko   ghar
3SG-GEN   friend-GEN   elder.sister-GEN   house
[[[[NP-G] NP-G   ]   NP-G   ]   N   ]
'his friend's elder sister's house' (fieldnotes, B. Bickel)

In more conservative varieties and in written Nepali, the *k*-marker would show agreement in gender (*sāthi-kī didi* 'friend's elder sister'). In all varieties, however, the *k*-marker has already lost one of its original adjectivizing properties: the marker is no longer able to embed adpositional phrases: while Hindi allows constructions like *mez-par-k-ī kitāb* (table-on-ADJZ-F.SG book) 'the book on the table' (Verma 1971:146), this use of the *k*-marker is not possible in Nepali (and so **ṭebul-mā-ko kitāb*, with *-mā* 'on, at, in', is ungrammatical; Narayan Gautam Sharma, p.c.).

HEAD MARKERS. All head-marking NP constructions in Indo-European are innovated. They all draw on pronominal elements, either via possessive pronouns (e.g. Afrikaans and other Germanic languages) or via anaphoric and/or relative pronouns (e.g. the ezāfe in Iranian). Head marking via possessive pronouns had a relatively brief life in the history of English. It developed in Middle English in the form of a nonagreeing, invariant form *(h)ys* (syntactically comparable to Afrikaans *se*).

(21) Middle English
to fortefy   hys   brethren   ys sayyngys
to strengthen   3SG.GEN   brethren   ys comments
[[[NP-G] NP   ] N-H   ]
'to strengthen his brethren's comments' (Allen 2008:247)

This construction competed with the *s*-genitive, which developed phrasal-affix status at about the same time (Allen 2008) and eventually completely replaced the head-marking construction (conceivably with support from the similar-sounding marker *ys*).

The Iranian ezāfe construction developed early on. An eighth-century BCE example is the following.

(22) Young Avestan (ca. eighth century BCE)
puθr-əm   yat̰ pourušasp-ahe
son(M)-ACC.SG EZ   Pourušaspa(M)-GEN.SG
[N-H   [NP-G   ]]
'the son of Pourušaspa' (Yašt 5.18)

The particle *yat̰* is formally the neuter form of the relative pronoun *ya-*, but it no longer shows agreement; instead it serves as a linker of a genitival attribute to its head. This type of construction quickly developed into the productive and multifaceted ezāfe construction characteristic of many Iranian languages, such as Persian, illustrated in example 7 above. The ezāfe was lost again in Ossetic. Evidence that it was present in earlier stages comes from remnant usages like the following.[9]

(23) Ossetic, Iron dialect
mæ   fɨd-ɨ   zærond
1SG.GEN   father-EZ   old
'my old father' (Thordarson 2009:109)

[9] The relevant marker (-ɨ) happens to be formally identical to the genitive case, resulting in the apparent synchronic puzzle of a genitive marking a head.

In Ossetic, modifiers normally precede the head, and according to Thordarson (2009: 109), constructions like 23 are semantically specialized for certain expressions of physical and mental properties and states such as ‘old’, ‘good’, ‘stupid’, and so forth. Critically for our current interest, in modern Ossetic, *ɨ*-linked postnominal modifiers occur in only a few fixed expressions (Belyaev 2010:298) and do not support any recursive NP embedding (David Erschler, p.c.).

Adpositions. Adpositions are not attested in adnominal use in Sanskrit, Avestan, or Old Persian, and such constructions are unlikely to have existed in Proto-Indo-Iranian, the common ancestor of these languages. Adnominal adpositions developed as a new type in some of the daughter languages, however. A case in point is Middle Persian, where *pad* ‘in, against’ is an adposition that governs the oblique case (which, however, is visible in only a few contexts, such as pronouns; see §10.5 in Supporting Material 1).

(24) Middle Persian (Zādspram, ninth century CE)
tār-kirb-ān pad čihr ud dēs ī Azdahāg
darkness-body-PL in shape and form EZ Azdahāg
[N [NP-P N-H [NP]]]
‘creatures of darkness in the shape and appearance of (the dragon) Azdahāg’
(Gignoux & Tafazzoli 1993:36)

The construction disappeared again in Modern Persian, since adpositions were reanalyzed as phrasal case prefixes that no longer assign case.

Adpositions also had a relatively fast turnover in Celtic: adnominal adpositions were reanalyzed as genitives in Middle Welsh and Modern Breton (cf. 17 above). In Modern Welsh, however, the phrasal genitive prefix newly acquired adpositional properties again (under influence from English). As such, it can be stranded.

(25) Modern Welsh
Lle ’dach chi ’n dod o?
where be.PRS.2PL 2PL PROG come.INF from
‘Where do you come from?’ (Borsley et al. 2007:116)

This reanalysis has not affected the possibilities for recursion.

(26) Modern Welsh
disgrifiad o-r rhes o dai
description(M) from-ART row(F) from house(M).[PL]
[N [NP-P [NP-P]]]
‘the description of the row of houses’ (Borsley et al. 2007:72)

Juxtaposition. In several ancient Indo-European languages, endocentric juxtaposition was not very prominent and became fully recursive only later. A case in point is Old Norse, where juxtaposition with more than two members is rarely attested (Carr 1939:200–201). The few cases that do occur either involve a genitive (27a) or are not recursive (27b).

(27) a. guðs- reiðis- verk
God(M).GEN.SG- anger(F).GEN.SG- act(NT).NOM.SG
[[[NP-G] NP-G] N]
‘act rousing the anger of God’ (Carr 1939:200)

b. hǫfuð- rað- gjafi
head(NT)- advice(NT)- giver(M).NOM.SG
[[NP-Ø] [[NP-Ø] N]]
‘chief counselor’ (Carr 1939:201)

In 27b, the first element (*hǫfuð* 'head') is not recursively embedded into an embedded element but modifies the unit *rað-gjafi* 'counselor' as a whole. Juxtaposition became freely available for recursion only later in the history of the branch. In modern Icelandic, for example, juxtaposition allows recursive interpretations (Harðarson 2016).[10]

(28) Icelandic

járn-	stál-	fótur
iron(NT)	chair(M)	leg(M)
[[[NP-Ø]	NP-Ø]	N]

'leg of an iron chair'

A similar development can be seen in Irish: whereas Old Irish did not allow juxtaposition of more than two nominal elements, this has become a popular strategy in Modern Irish (see §8.4 in Supporting Material 1). Similarly, while Latin blocks recursive juxtaposition (§13.3), Italian—unlike many other modern Romance languages—now allows it (as in, for example, *programma riciclo materiali* 'material recycling program'; §13.2).

Indo-Aryan illustrates the opposite process, where recursive juxtaposition became unavailable for NP recursion over time. As observed above (12), juxtaposition freely allowed NP recursion in Sanskrit and became particularly popular in Late Sanskrit and Pāli. Despite this prominence, several modern daughter languages have come to disallow juxtaposition and now require case or other markers instead. This is so, for example, in Nepali, where one cannot juxtapose *māsu* 'meat' and *tarkāri* 'curry' to form **māsu-tarkāri* 'meat curry'. Instead, one needs to use a genitive affix: *māsu-ko tarkāri* (cf. example 20 above). This contrasts with Sanskrit borrowings in Nepali, where juxtaposition is still abundant, for example, *sthāna-nāma-koś* 'place-name-dictionary' (the title of a publication by the Nepal Academy). A similar fate for juxtaposition is found in most other Indo-Aryan languages in our sample, except in Oriya and Sinhala (see §§10.6 and 10.8, respectively, in Supporting Material 1).

3.4. Phylogenetic distribution. The survey in the preceding section shows that each NP type has become newly available for recursion at least once in historical time and has become unavailable at least once. This means that the system was sufficiently dynamic for our hypothesis to be testable: some of the types developed and disappeared again within less than 500 years (e.g. head marking for recursion in English, new genitives in Middle Welsh) and many within less than 2,000 years (e.g. head marking for recursion in Ossetic, juxtaposition in Nepali). There were thus many situations in which a choice arose between keeping and not keeping a specific type for recursion. Indeed, the high dynamics of the types suggests that it would have been perfectly possible for an Indo-European language to completely lose all types simultaneously. This would then block NP recursion entirely, mirroring what appears to have happened in Pirahã. If this happened many times, it would falsify our hypothesis.

To test this, we compiled a systematic sample of Indo-European languages (Supporting Material 1). With this sample, we first assess below whether any historically attested or extant language lacks NP recursion across all types. However, synchronically attested distributions can be deceptive (Maslova 2000, Cysouw 2011). For example, even if some feature or state dominates the attested languages of a family, it is entirely possible that it was dispreferred in the unknown past. The problem is illustrated schematically in Figure 1.

[10] The expression also allows a nonrecursive interpretation as 'iron [chair leg]', that is, 'iron leg of a chair' (Harðarson 2016).

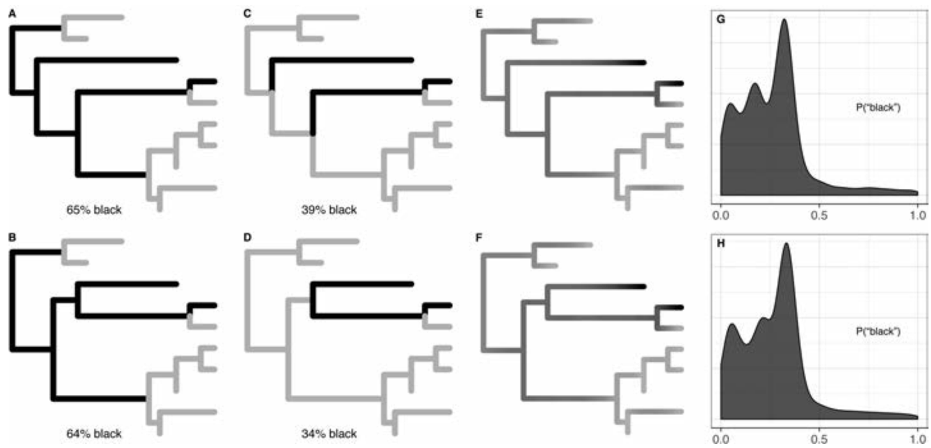

FIGURE 1. Different historical scenarios compatible with the same synchronic data. A–D: contrasting possible histories A vs. C and B vs. D, which are compatible with the same synchronic distribution of 'black' (20%) vs. 'gray' (80%) languages (= tips of the trees), assuming different tree topologies across the two rows (A and C vs. B and D, respectively). E–H: posterior probability distributions of states estimated by the methods explained in §3.4, visualized as densities over time in a gray-to-black gradient (E and F) and as density plots for the probability of 'black' across samples of thirty-year intervals in each tree (G and H).

Assume that 80% (eight of ten) of the attested languages in a family are in state 'gray' (which could stand for 'allows syntactic recursion'), as indicated by the colors at the tips of the tree. One is tempted to conclude that 'gray' is the preferred, dominant state. However, keeping the same synchronic frequencies, it is entirely possible that the family was in fact dominated by 'black', regardless of what exact tree structures one assumes (A and B in Fig. 1). Of course, it is also possible that the family was indeed dominated by 'gray' (C and D). The problem is that we cannot tell by inspecting synchronic frequencies alone. Sometimes assuming maximum parsimony for the number of transitions might favor a certain scenario—for example, scenario D assumes one change less than B—but this is not always possible: scenarios A and C involve the exact same number of state transitions (namely three), and there is no good reason to assume maximum parsimony to begin with, especially for changes that seem as rapidly reversible as the ones we observed for NP types and their availability for recursion. Qualitative reconstruction of proto-syntax could in principle resolve the problem, but such reconstruction is exceedingly difficult (or perhaps completely impossible) because abstract syntactic properties of the kind we assess here form no natural cognate sets that would be rich enough for deciding between alternative reconstructions.

In response to these problems, rather than debating possible histories, we turn to probability estimates below. We use Bayesian phylogenetic methods to estimate the posterior probabilities of each type throughout the history of the family. We explain the method below, but panels E–H in Fig. 1 show the posterior probability distributions that the method would estimate in the schematic example (assuming branch lengths with realistic time depths).

The distribution is shown as a gray-to-black gradient in panels E and F and as a density plot across sampled time intervals in panels G and H. Here, results suggest that it was always slightly less probable for a language to be in state 'black' than in state 'gray', under either of the two tree structures.

For both the qualitative and the quantitative study we sampled languages so as to cover one representative of each branch that was separated from all other branches for at least about a thousand years. So, for example, we include both English and Afrikaans, but not both Afrikaans and Dutch.[11] In addition we covered as densely as possible all earlier and intermediate stages of languages. This generates sufficient resolution for phylogenetic methods, while keeping data acquisition within reasonable limits.

ATTESTED LANGUAGES. The sample is summarized in Figure 2. The tree is a MAXIMUM CLADE CREDIBILITY tree taken from Chang and colleagues' (2015) ancestry-constrained phylogeny (see Supporting Material 2 for details on the mapping of languages between the two data sets and particularly figure 2 there for a visualization of the data mapped to an alternative tree from Bouckaert et al. 2012). The data in Fig. 2 shows that in every language, one or more types of NP embedding are unavailable for recursion. However, no language developed in the direction of Pirahã: in each language of our sample, there is at least one NP type that allows recursion. This supports our hypothesis that languages prefer developing and maintaining structure-building operations that include syntactic recursion (see §2). But, as noted above, synchronic distribution can be deceptive, and we turn to probabilistic methods to estimate the most likely pattern of how NP recursion evolved over time.

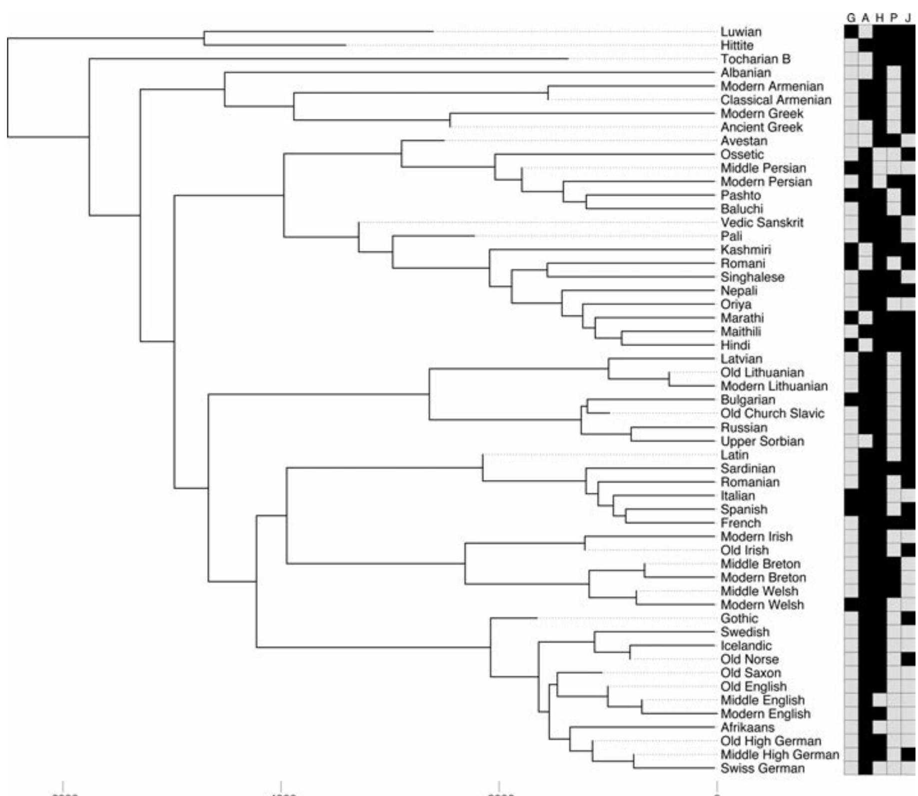

FIGURE 2. Summary of the analyses in Supporting Material 1. NP types: G: genitives, A: adjectivizers, H: head marking, P: adpositions, J: juxtaposition. Gray: type is available for recursion; black: type is not available for recursion. The tree is a maximum clade credibility tree estimated by Chang and colleagues (2015), with our additions.

[11] For this we rely on the tree topology and date estimates from Chang et al. 2015, except for Slavic and Romance, where their approach underestimates the age of speciation.

Probability estimates.

Methods. We model the availability vs. nonavailability for recursion of an NP type as discrete states in a continuous time markov chain evolving over the phylogeny and estimate the rates of transitions between these states in a Bayesian framework (using the package BayesTraitsV2; Pagel & Meade 2014). For each type, we fit models assuming equal rates, that is, the same rates for gaining and losing a type for recursion, and models assuming unequal rates, that is, evolution that is biased toward one of the two options. We then compare the likelihood of these models with Bayes factors.[12] The best-fitting transition rate estimates are then used for stochastic character mapping (Nielsen 2002, Huelsenbeck et al. 2003, Revell 2012). Stochastic character mapping simulates histories of state change in a tree, given transition rates and the states in the tips; for example, an NP type might be available for 500 years, then be unavailable for 1,000 years, then emerge again, and so forth. There are many different ways in which such a history (technically known as a character map) is compatible with the transition rates and the data. The solution to this problem is to estimate the posterior probability distribution of character maps through Monte Carlo Markov chain sampling. The posterior character maps are then aggregated into density estimates over time by binning the branches in the tree into time intervals of about thirty years. For this, we use a procedure introduced by Revell (2013) for visualizing stochastic character maps on a tree (as illustrated by panels E and F in Fig. 1). Finally, we combine the estimated density distributions from each NP type and compute for each time interval (bin) the probability that at least one type is available for recursion. The time interval can also be thought of as a diachronic trial, in which we assess the posterior probability of a type being available or not. This corresponds to the visualizations in panels G and H in Fig. 1.

Phylogenies. Since the topologies and branch lengths of trees are themselves uncertain, we estimate the posterior probabilities of stochastic character maps not on any one consensus or summary tree, but on a large sample of posterior trees. For this we used the posterior sample of Indo-European trees estimated by Chang and colleagues (2015). In order to assess whether our results are robust against the assumptions of this model, we furthermore replicated all analyses on the tree sample estimated by Bouckaert and colleagues (2012).

Our data set includes several extinct languages that are not covered by either of these tree samples because the lexical data were not sufficiently worked up or are insufficient for reliably inferring phylogenies (Chang et al. 2015:219–12): Old Saxon, Old English, Middle English, Middle High German, Middle Welsh, Middle Breton, Middle Persian, Old Lithuanian, Pāli, and (in the case of the Chang et al. trees only) Luwian. In order to include these languages in our estimates, we grafted them onto the tree sample. The age of each language was randomly sampled from a uniform distribution bounded by the earliest and latest attestation dates (see Supporting Material 2, §1). The resulting tree sample is visualized in Figure 3 as a DensiTree, which gives an impression of the amount and loci of phylogenetic uncertainty (Bouckaert & Heled 2014). (For a similar representation of the Bouckaert et al. 2012 tree estimates, see figure 4 in Supporting Material 2.)

[12] Bayes factors (*BF*s) are reported on a log scale and are defined as double the difference between the log marginal likelihood of the more complex model (assuming unequal rates) and the log marginal likelihood of the simpler model (assuming equal rates). *BF*s smaller than 2 are conventionally interpreted as only weak or no evidence for the more complex model, *BF*s higher than 2 as positive, higher than 5 as strong, and higher than 10 as very strong evidence for the more complex model (e.g. Cysouw 2011, Dunn et al. 2011, Pagel & Meade 2014).

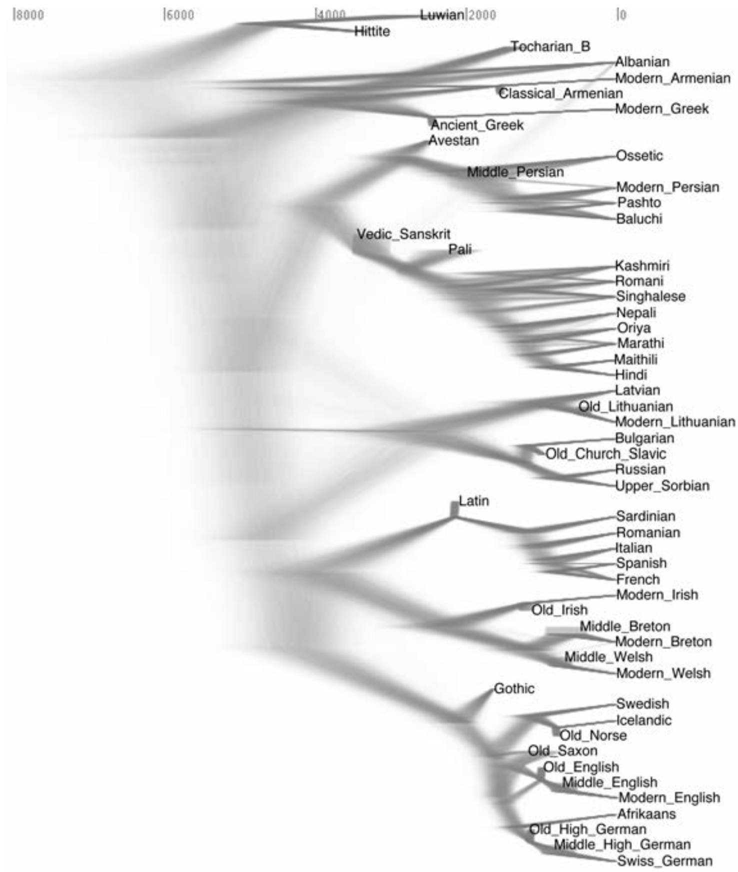

Figure 3. DensiTree representation of the posterior tree sample in Chang et al. 2015. In order to match our data set, we removed some and added other languages, as described in the main text and with further detail in Supporting Material 2.

We estimated transition rates on the full posterior tree samples.[13] But for stochastic character mapping we used a random subset of 1,000 trees only because larger samples are computationally extremely expensive, with no apparent gain in estimation quality.

Results and discussion. Results across ten replications of the transition rate estimates suggest that for adpositions and juxtaposition, there is no evidence for biased evolution—that is, models assuming equal rates fit the data better (adpositions; $BF = 3.53 \pm 0.39$) or just as well (juxtaposition; $BF = 0.81 \pm 0.13$) as models assuming different rates. By contrast, genitives, adjectivizers, and head marking show strong evidence of biased evolution. Genitives favor evolution toward being available for recursion ($BF = 13.22 \pm 0.18$), while adjectivizers and head marking favor evolution away from being available for recursion ($BF = 7.03 \pm 0.49$ and $BF = 19.58 \pm 2.25$, respectively) (for a visualization of the rate differences, see figure 7 in Supporting Material 2). Results were very similar when we replicated the analysis on the Bouckaert et al. 2012 trees, except that the evidence for a bias against recursively used adposition structures was slightly weaker ($BF = 5.36 \pm 0.62$) (see table 1 in Supporting Material 2).

[13] See Supporting Material 2 for further details, including a discussion of our assumptions about priors.

The positive bias for recursion with genitives is expected to reach stationarity within a period of about 5,700 years (and about 4,000 years when assuming the Bouckaert et al. 2012 trees; see §2.6 in Supporting Material 2). At this point, which has been reached by now, there will always be an estimated 79% of Indo-European languages that have recursive genitives and 21% that do not (or 77% vs. 23%, when assuming the Bouckaert et al. trees). Comparing the stationary distribution with the synchronic distribution (where 80% of languages have recursive genitives) suggests that the synchronic distribution reflects the bias toward genitives reliably in the Chang et al. 2015 trees but slightly overestimates the bias in those of Bouckaert et al. 2012.[14]

Our hypothesis predicts that languages prefer NPs with syntactic recursion. The bias in genitives supports this, as there will always be more than almost four times as many languages where at least genitives are available for recursion. This still leaves a bit over 20% of occasions where genitives are unavailable as well. In order to assess the impact of this over diachronic trials, we turn to the results from stochastic character mapping. These are summarized in Figure 4. The figure plots the posterior probabilities of a type being available over 2.8 million time intervals of about thirty years. These intervals are sampled from the character maps across trees. The results based on the Bouckaert et al. 2012 trees are very similar (see figure 23 in Supporting Material 2).[15]

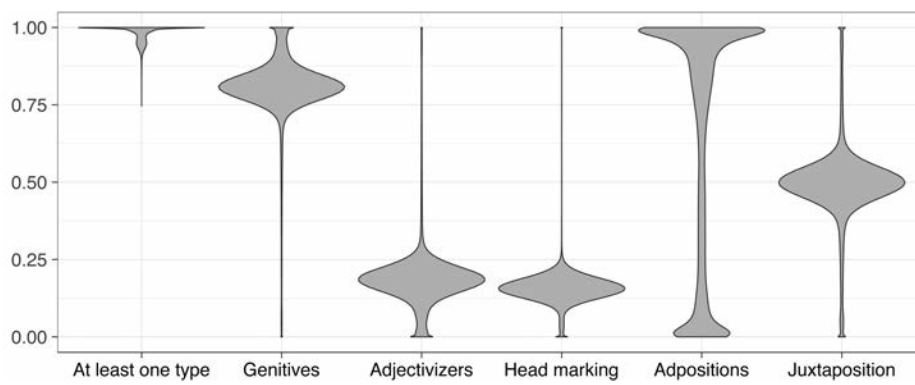

FIGURE 4. Posterior probabilities of types being available for recursion in each speaker generation, that is, diachronic trial. The probabilities are plotted as density distributions mirrored on the vertical axis ('violin plots'; Hintze & Nelson 1998): the wider the shapes, the greater the probability values across all sampled trials.

The distribution of probabilities varies greatly across types, and none is guaranteed to be available in each generation of speakers. However, the combined probabilities of at least one type (leftmost column) reaches an estimated mean of 98%. Results based on Bouckaert et al. 2012 are very similar (see §3.6 of Supporting Material 2).

These results provide strong support for our hypothesis: while on about 20% of occasions, the preferred type in Indo-European, genitives, is unavailable for recursion,

[14] Note that if we knew only the currently extant languages, with 72% recursive genitives, we would underestimate the strength of the bias. This should caution us further against quick conclusions based on synchronic samples.

[15] Sections 3.3–4 of Supporting Material 2 include visualizations of stochastic character maps on the maximum clade credibility trees (corresponding to panels E and F in Fig. 1) in order to give a sense of the estimated dynamics, both for each type separately and for the combination of types. Such a visualization is not possible when stochastic character mapping is performed on entire posterior tree samples, as we do here for the main analysis.

in these occasions chances are close to 100% that at least one other type will be available instead.

4. Discussion and conclusions. Our hypothesis predicts that within any given phrase, there tends to be at least one type that allows syntactic recursion. This is confirmed for Indo-European NPs both qualitatively (all attested languages in our sample have at least one such type) and quantitatively (the probability of having at least one type in any given time interval is estimated to be close to 100%). Some NP types are disfavored to various degrees; that is, they are likely to be lost or not to develop at all for recursion. But we find that whenever these types become or remain unavailable in a language, there is a very strong bias for developing or retaining an 'escape' type that allows recursion.

Our hypothesis maintains that this evolutionary bias is caused by a processing principle that favors syntactic recursion. Alternatively, one might attribute our findings to a preference for having genitives, since this is the dominating escape type in Indo-European. However, this alternative has two shortcomings. First, it does not does explain why in those cases where genitives are unavailable for recursion, this is compensated for by alternative strategies for NP recursion (e.g. by adjectivizers in Luwian and in several modern Indo-Aryan languages). Second, a preference for genitives lacks a natural explanation; that is, there is no intrinsic reason for them to be preferred. We know from other families that, for example, head-marking strategies can just as well be preferred, as is generally the case around the Pacific (Nichols 1992, Nichols & Bickel 2005). And among the dependent marking types that are prevalent in Eurasia, genitives are only one possibility, along with adpositions and adjectivizers.

Given this, we submit that the best explanation for the evolutionary bias we find is indeed a processing principle that favors not a specific NP type, but NP recursion in at least one type, regardless of which type that is. If this explanation is on the right track, it challenges the idea that syntactic recursion in NPs is a mere option (Fitch et al. 2005, Watamull et al. 2014), with no implications for crosslinguistic distributions. Given the evolutionary bias we detect, there must be another mechanism beyond this, and given the preference for recursive operations across many different domains of human cognition (§2), a processing principle seems the most likely candidate for this mechanism. In this light, it seems that the link between syntactic recursion and recursion in the general, mathematical sense is more fruitfully explored through research on processing and its effect on language evolution than through controversial (Pullum & Scholz 2010, Kornai 2014) assumptions about the role of infinite counting in the description of syntax or linguistic creativity.

In order to fully establish our theory, however, at least three issues need to be worked out. First, our predictions need to be tested in a larger sample of diachronic transitions from other families and continents. We are confident that results will replicate. One reason is that the typological record suggests that there are many more languages that allow NP recursion than languages that do not allow NP recursion. As we noted, synchronic generalizations of this kind can be deceptive, and some previous generalizations have indeed been challenged by phylogenetic and other diachronic analysis (Dunn et al. 2011, Bickel et al. 2014), but when effects are as strong as in our case here, we would not expect this to happen. Another reason for confidence is that the Indo-European case is relatively strong evidence by itself. Because we relied on posterior samples of trees and stochastic character maps, our results are not based on a handful of surveyed time intervals (generations), but on a sample of about 2.8 million such intervals. Also, given the geographic spread of the family, these transitions occurred in very different contact situations and sociolinguistic environments. This makes it plausible that our results reflect principles of diachronic change and are not just specific to Indo-European.

The second issue that needs further research is the scope of the theory. Here, we focused on NPs only. With regard to sentence-level syntax, it remains an open question whether syntactic recursion or simple conjunction is preferred. Again, for this a larger sample of data would be needed. Similarly, with regard to within-word syntax (morphotactics), it is unclear to what extent recursive operations dominate. Many word structures appear to be built by simple string concatenation, although explicitly recursive operations are also attested, for example, in derivations like *anti-anti-establishment* and, in some languages, also in verb compounding, which in the Tibeto-Burman language Chintang involves recursive additions of partially inflected stems (Bickel et al. 2007).

A third issue that remains open concerns the biological basis of our theory. So far, we have left it open whether the preference for syntactic recursion is caused by general efficiency gains when using the brain's broader faculty for recursion or whether the preference is mediated by the specific advantages of recursion for building hierarchical structures (dendrophilia). Further insight here will depend on neurobiological research that systematically disentangles recursive from hierarchical operations and compares each of these across cognitive domains (Martins et al. 2014, Fischmeister et al. 2016). At present we cannot locate the source of syntactic recursion sufficiently well.

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