ON THE ℇ-MERGENCE OF VERBS

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Abstract: *A model of semantic Merge based on the well-known X-bar theory of formal grammar is proposed. The model represents the phrase as a result of recursive mental procedure over mental representations of Entities. This is tied to facts from brain research and to propositions from language evolution and child speech development. The resulting tree is that of Fibonacci. When rules borrowed from linguistics are applied to this model and it is described by a formal recursive procedure, it turns out that no more than three Entities can participate in the mental creation of the argument structure. This begs the question of the valence of verbs, assuming that their image received linguistic expression after it happened to the Entities.*

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Introduction

A well-known and fundamental question in linguistics is how syntax interacts with semantics. The separation of cognitive processes from linguistic processing has given rise to a number of misunderstandings, among them the question of which is primary, language or thinking abilities. The reasoning below aims to propose a model of recursive information processing that can explain the process of syntactic structuring at a formal level as a process that is based on operations defined by linguists as syntactic and semantic and that modern science has shown are indeed performed by the brain. The process modeled further concerns the mental creation of what is called here a mental image of a verb.

The main linguistic theories focus on the rules and mechanisms following which a sentence is structured. It is said that, in a broad sense, a Merge operation creates complex structures such as phrases and sentences by combining smaller linguistic elements. Merge is recursively applicable over its own output and can generate an infinite number of sentences by applying over a finite number of language units. Hence, it is accepted that recursion and merge are at the core of language faculty. Language faculty is a faculty of the brain.

It is still not completely clarified how the brain operates on language. Hagoort (2019) describes a much more complex picture of interacting brain areas than in the classical neurobiological model of language that concentrates on the known Broca's and Wernicke's areas. Language requires the involvement of multiple networks with functionally nonoverlapping contributions. Specialized studies found that the brain represents grammars in its connectivity, and its ability for syntax is based on neurobiological infrastructure for processing structured sequence (Peterson and Hagoort, 2012). Some questions arise – can the brain execute recursively and can it perform operations that correspond to the linguistic Merge.

The recursive processing employed in mental calculations, in general, appears not to be restricted to the domains of language – it was found in music, vision, action, and pragmatics. Examples show that recursive reasoning happens spontaneously. It seems this capacity is inborn and not unique to humans. Ferrigno, Cheyette, Piantadosi, and Cantlon (2020) used a nonlinguistic sequence generation task to test whether human subjects and monkeys generalize sequential groupings of items to a recursive structure. Children (aged 3 to 5), U.S. adults, and adults from a Bolivian indigenous group spontaneously induced recursive structures from ambiguous training data. And monkeys did the same, but only with additional exposure. Studies in animal cognition have shown that recursion exists in animal calls. There is no indication, however, that the participating parts have meaning (see Zuberbühler, 2020 for a recent overview). The proposed in linguistic Merge operates, however, on meaningful units.

Although the brain can run a recursive processing, this does not imply that languages are also recursive. Many examples of present-day languages show that the ‘linear grammar’ is not an uncommon phenomenon. The most famous examples are: the indigenous Amazonas language Pirahã with no syntactic recursion (no phrase within phrases, see Everett, 2013) and Riau Indonesian, which does not make use of recursion and the word order is based on semantics (Gil, 2005, 2017).

There are many results concerning the neuronal basis of the operation Merge. Based on brain imaging and experiments, Zaccarella and Friederici (2015) examined the sub-anatomical specificity for the process of syntactic binding and found that it has a strict neural basis in Brodmann Area (BA) 44 (roughly – Broca’s area). The constraint localization of the activity and its consistency across the participants, the authors say, point toward the fundamental neurobiological nature of the operation Merge itself, thereby providing a novel view on the relation between linguistic theory and neurobiology. Further, Zaccarella, Schell, and Friederici (2017), based on a meta-analysis, suggest that the linguistic Merge is biologically “implemented” by a “syntactic processor” in BA44 and an “integrative processor” in pSTS/STG (roughly – Wernicke’s area) which communicate to each other along dorsal white matter fascicles. Grodzinsky, Pieperhoff, and Thompson (2021) did a retrospective review of fMRI studies of complex syntax based on a rigorous selection that resulted in seventeen studies with 316 participants. The extant data decisively point to the Broca's region as the main locus of complex receptive syntax with the involvement, to a lesser extent of the Wernicke’s area. The authors conclude that the neural bases for syntactic processing in the human brain evince remarkable stability across the results obtained so far.

Brain imaging techniques have allowed identifying the dynamic characteristics of Merge too. Nelson and colleagues (2017) analyzed the activity evoked at multiple sites of the left hemisphere while French- and English-speaking adults read sentences word-by-word. Brain activity increased with each successive word but decreased whenever several previous words could be merged into a syntactic phrase. The decrease, the authors suppose, corresponds to a process of re-encoding of the merged semantic images into a new neuronal population vector, normalized to the same sparse level of activity as a single word. It can be said that at the level of brain processing there occurs a mental operation that produces a novel unit of meaning by 'merging' the components of the sequential input. In the experimental results of this study, it is seen that when listening to a sentence, the brain activity increases with each word in the sequence and drops sharply, apparently merging the word images into a single image. It is important to note that this can happen before the appearance of the verb in the sequence. This suggests that when the sequence of words induces a comprehensive mental image, they are spontaneously merged without a verb.

These findings are not in conflict with the existence of languages with linear grammar. The input is in all cases sequential and it shouldn't matter how the brain processes the input – it produces novel informational units by merging the components of the input into a novel larger representation of meaning.

It comes out that the brain can perform "Merges" when decoding the linear input. However, the question of how the brain came to produce language remains. How words appeared is easier to imagine and the only point which is relatively clear. But the question about how phrases appeared and became expressed in language stays unexplained. It is reasonable to assume that some individual mental images were joined to form larger meaning-units. Once having a language as we do, it seems natural to imagine that the sentence exists "because" of the predicate and to state that the verbs "select" their arguments. However, this verb-centered picture reflects most likely the obtained result and not the reason for the attendance of a sentence as a meaning unit. What were the primary mental images that existed labeled in the primitive languages which were "merged" to produce larger meaningful substance and to establish one day what we call now a sentence?

From the perspective of cognitive science, Entities are the primary mental images. This is discussed in several key sources that provide an in-depth analysis of mental imagery, including how it is formed, stored, and manipulated in the brain (see e.g. Barsalou, L. W., 2008 and Tversky, B., 2011). Entitles are usually expressed by nouns at the level of language. Research in child language confirms that the category of nouns is conceptually more basic than the category of verbs. Many argue that nouns are learned earlier because their referents are more accessible than those of verbs. This distinction is based on a preexisting perceptual-conceptual difference between Entity-concepts (persons or things) and predicative concepts (activity, change of state or causal relations). Since the meaning of a verb depends on the arguments (nouns) that it takes, scientists in the domain of child language propose that children need to establish a collection of nouns before they can learn verbs (see Waxman et al., 2013).

Fundamental theories in the domain of evolution of language agree with the inference coming from child language. For example, Deacon (1997) maintains that verbs may have been a late addition to language, and that early human language may have consisted primarily of nouns and simple descriptions of their properties. A recent essential work (Hagoort, P. (Ed.), 2019) discusses that the evolution of language may have been driven by the need to communicate about concrete Entities, and that verbs may have emerged later as a way to talk about events and actions.

The assumption that conceptualization abilities and primary mental operations trigger syntactic abilities is sturdily supported by recent research and analyses in cognitive linguistics and the evolution of language. For example, Hillert (2021), considering a broad range of empirical data, argues that (as proposed by Chomsky) syntax is a modality and domain-independent capacity of the human mind which follows innate non language-specific universal principles.

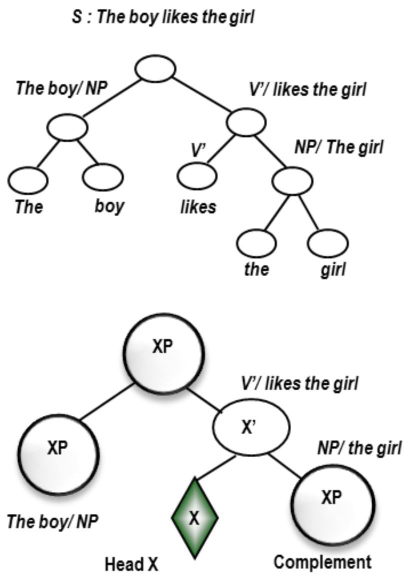
But there is, however, a lap – what information processing mechanisms allowed the grain to "produce" language with larger information units – sentences with syntax. Next, an attempt is made to relate the operations of syntax known in linguistics and supported by brain research to an informational model of phrase creation, more precisely, to the creation of a mental image of a verb that links the images into a phrase.

Linguistic Preliminaries

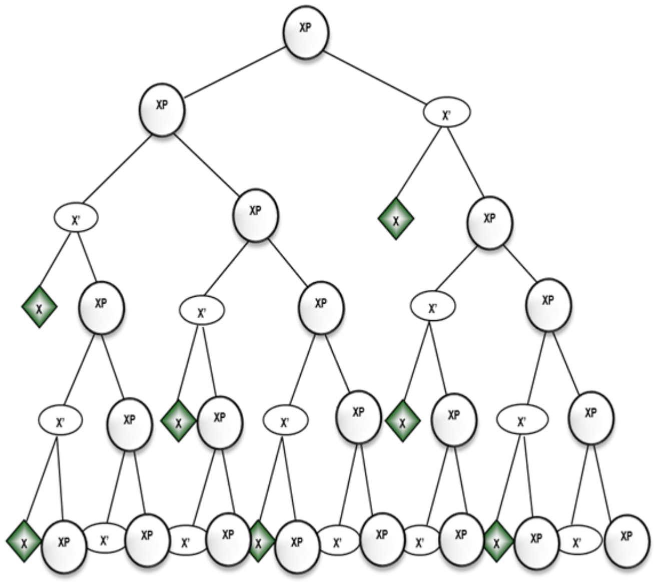
According to Chomsky's traditional theory (Syntactic Structures, 1957), syntax is governed by rewriting rules. This is represented graphically in Figure 1.a, which illustrates the X-bar theory. In this theory, phrases consist of a central element called the 'head', representing essentially a verb, which is accompanied by other non-central elements to form a larger structure. The theory uses XPs to represent phases, X's for intermediate projections, and Xs for heads. Figure 1.b shows "bare phrase structures" which are a generalized version of the traditional X-bar theory. The tree in Figure 1.b has three types of nodes: XP, X, and X'. There is a double-step recursion where each XP has two sons (one XP and one X') and each X' has two sons (one XP and one X). The tree "works" bottom-up by merging two elements at each step. Each step adds a newly introduced element to the already formed pair. To represent syntactic structures are used only binary trees because Merge is assumed to be necessarily binary.

Merge combines two syntactic objects to create a new syntactic element, and this process can be repeated to create more complex structures. For example, the verb "likes" and the nominal phrase "the girl" are merged to form a verb phrase (Figure 1.a). This theory has been further developed and analyzed by scholars (see Berwick & Chomsky, 2016; Chomsky, 2017; as well as Hillert, 2020 for analysis and overview of Merge). Merge is a recursive syntactic operation that can generate sentences by combining its own output from the previous step. As discussed, many examples of present-day languages show that the non-recursive, 'linear grammar' is not an uncommon phenomenon. At the same time, it is shown that the brain performs recursion and that its language areas have an activity that astonishingly corresponds to Merge when treating a linear input. In the analysis proposed here, Merge and recursion are assumed to be biologically embedded functions of the brain.

Linguistics makes efforts on the road to mathematical descriptions. Regarding the relationship between the syntactic tree and the language viewed as a biological phenomenon, Carnie and Medeiros (2005) have proposed that a number of unexplained properties of the grammar find a functional explanation, if we view them as correlates of a general desire for the grammar to maximize trees in such a way that they result in a Fibonacci-like sequence. They consider a maximal, full tree generated by Merge as the one in Figure 1.b. and report that the number of XPs in each level follows the Fibonacci sequence. They propose that if grammar is aiming towards a structure where a Fibonacci sequence of XPs is required, then a mechanism for determining "XP" hood is necessary. They theorized that these things might follow the physical properties of the universe that push biological systems into particular mathematical patterns, proposing that: "Syntactic structure, like the stripes of zebras and the petals on a flower, strives towards the particular mathematical symmetry found in the Fibonacci sequence."



a.



b.

Figure 1. a: Classical representation of a syntactic tree;
b: General representation of x-bar tree

Entities-based syntax

Back to mathematics, the formal representation of syntax presented in Figure1.b faces three main problems. The first problem is the practical difficulty of transforming this recursive structure into a linear structure because it is bottomless. While linear languages exist, a solution to the bottomlessness problem has not yet been found. The second problem is the relationship between the processing of the syntactic tree and the semantic system. The tree stays isolated and does not suggest relations with mental images. The third problem is related to the cognitive resources required for processing, particularly working memory resources. The tree cannot be with an undefined bottom, some constraints have to be included. These problems have not yet been fully resolved.

In previous work (Slavova, V., & Soschen, A.,2007; 2009; 2015), it has been shown that when a syntactic tree is reduced to a tree connecting only the arguments in the sentence, it becomes a Fibonacci tree. The reasoning that led to this tree is briefly presented next.

The formal steps proposed to address the three problems mentioned above were performed by initially limiting the height of the tree. The three different types of nodes in the original tree have different syntactic interpretations and different properties in the language. Very generally speaking, the rule supposed to determine the form of the tree in Figure 1.b. comes from the fact that the leaves X are, roughly speaking, verbs. If the Xs remain as leaves, the structure is not strictly defined because the concrete number of arguments depends on the “selection properties” of a particular verb. The intermediate projections X’ were eliminated too because according to linguistic theory, they are invisible for computation.

The classical syntactic tree from Figure 1.b. was covered with a tree that relates only the XPs. That resulted in a Fibonacci tree, as shown in Figure 2.a. This well-known structure has several advantages. First it can be clearly and correctly defined based on its height as follows: “An XP tree of Height H consists of a root node XP, to which two sub-trees are attached – one is an XP tree of Height H-2, the other is an XP tree of Height H-1. The XP tree of Height 0 has 0 nodes, the XP-tree of Height 1 has one XP node.”

One more reason leading to the reformulating of the syntactic tree to a Fibonacci tree is related to the ‘biological reasoning’ suggested in the Minimalist program (Chomsky 1995). The idea, proposed as mentioned by Carnie and Medeiros (2005), advanced in Soschen (2008) and further developed in common works (Slavova, V., & Soschen, A.,2007; 2009; 2015), is that the linguistic system and living systems, both are characterized by a behavior aiming at conserving energy. As known, in biological systems there exist several elements that follow the rules of the Fibonacci sequence. Many of them have the exact form of a Fibonacci tree, or of ‘golden spirals’ (logarithmic spirals whose growth factor is φ, the golden ratio), thus providing examples of optimal growth systems. The main hypothesis maintained was that syntactic structures should comply with the principle of efficient growth.

The obtained Fibonacci tree relates the arguments in a sentence in a unique way. That is why the resulting tree was called an argument-based Fibonacci tree.

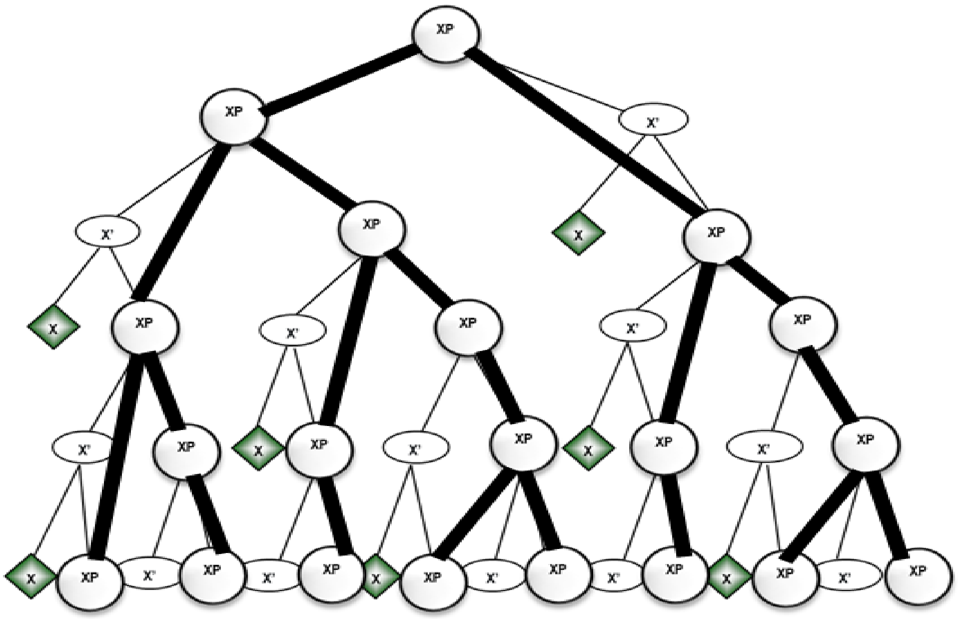
This viewpoint is in contrast with verb-centered models of syntax. Although the central role of the verb in the syntactic structure is largely accepted, possibly by heritage, there are several specialized studies that show the dominant role of arguments (see e.g. Bornkessel-Schlesewsky et al, 2011)

The Fibonacci tree in Figure 2.a becomes a merge-processing tree if every node is double branching as shown in Figure 2.b because the operation Merge always requires two participants. The tree in Figure 2.b is augmented with edges that relate empty sets Ø and mental images of entities E to comply with this syntactic requirement for double branching of each node. This extends the process presented by the obtained structure to the level of mental representations and semantics.

It is considered in linguistics that a predicate (verb) needs its arguments to complete its meaning. No linguistic theories suggest that the relations between the Entities in an event or action have “pushed” the existing mental mechanisms to create the concept of the predicate.

The arguments in a sentence are semantic Entities. As discussed, Entitles are proposed to have arisen first in language. The tree in Figure 2.b relates Entities. The reasoning that follows probes the hypothesis that Entities were semantically merged to create a mental image that corresponds to a verb.

a.



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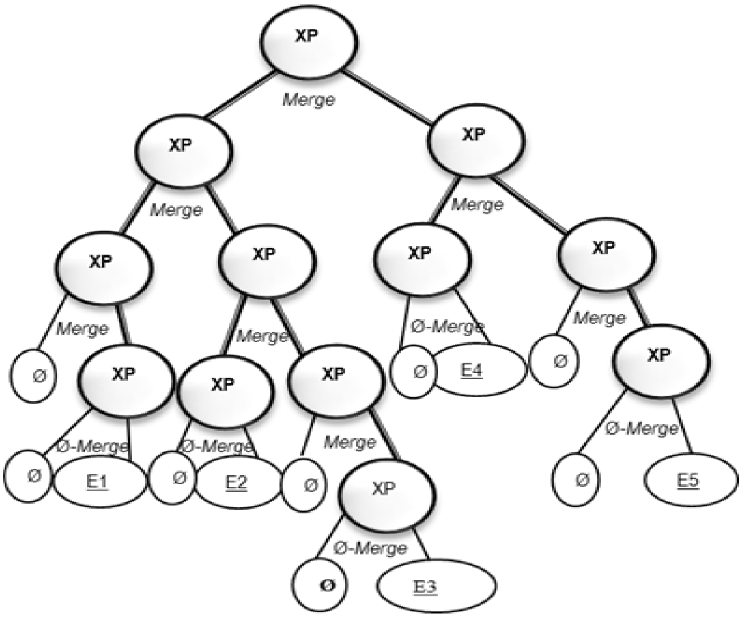


Figure 2. a. A Fibonacci tree relating the arguments XP in a classical syntactic tree; b. The Fibonacci tree enlarged to comply with the syntactic requirement of double branching.

The semantic merge

Suppose that at the initial moment of the development of linguistic exchange Entities were given names. The phrases express thoughts to describe observed scenes and events in which these Entities participate. That is, verbs emerged as a result of the mental activity of binding the Entities involved into a common semantic picture and this semantic merging of Entities into a common mental picture has engendered the verb.

The first task from the point of view of the semantic model proposed here is to relate the Merge-based processing with semantic representations. Merge as a cognitive function has been shown to apply in several domains such as figurative language, music, arithmetic, etc., and to produce an item with a 'novel meaning'. The creation of novel meaning is a feature of Merge which has been shown to exist in the communication calls of monkeys and nonhuman primates (see Hillert, 2020 for an overview of the cognitive domains in which Merge has been shown to apply and of the evolution of Merge).

Merge is an operation that combines items into novel meaningful units.

A solution of the task to relate the processing derived from the classical syntactic tree with semantic representations is proposed in the linguistic model put forward by Soschen (Soschen 2006, 2008). Two essential operations are proposed there – Ø-Merge and type-shift. The idea of Ø-Merge and "type-shifting" follows the proposed in a well-known work of Jackendoff (1977) on cognitive grammar where the concept of "Ø-syntax" was introduced. In this view, the result of Ø-Merge operation is a singleton set (XP) that is ready to be involved in further syntactic constructions. Type-shifting refers to the process by which a lexical item or expression changes its semantic type, allowing it to combine with other items or expressions. According to Jackendoff, type-shifting is a crucial aspect of human language and is closely linked to the conceptual and cognitive structure of our minds.

The tree in Figure 2.b. can be seen as an operator – it 'performs' a bottom-up Merge.

The processing in the formal model presented here starts with the operation Ø-Merge. The operation Ø–Merge produces a XP by integrating the mental image of an entity E (Figure 2.b.) at the level of language. The operation Ø-Merge indicates the transformation from a mental unit to a lexical item XP (singleton set) ready to be involved in language constructions (Figure 3.a). The introduction of Ø-Merge is important for the general interpretation of the mental processing, as it provides a rule for producing sets that are the starting point in both syntactic (i.e. sentence formation) and semantic (i.e. conceptual) processing.

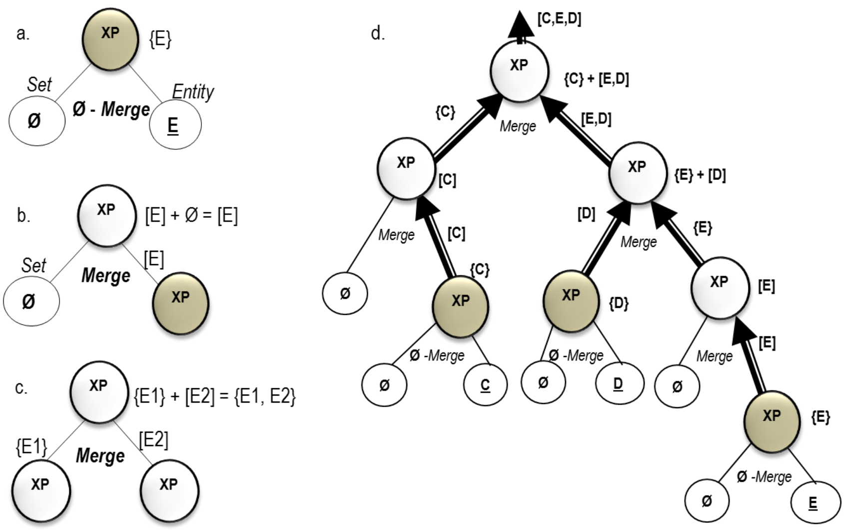


Figure 3.a. Ø-Merge; b. Merge of an unbreakable entity with an empty set Ø; c. Merge of a set and an unbreakable unit; d. Bottom-up Merge-processing with Type-shifts.

From the point of view of the corresponding linguistic theory, to form a novel constituent one of the elements gathered by Merge has to be a set ready to include other members, and the other element have to be an unbreakable construct.

Merge is defined in linguistics as asymmetric operation that has one entry for a set (marked with '{}' in Figure 3) and another – for an unbreakable entity (marked with '[]' in Figure 3). When an unbreakable entity is merged with an empty set Ø, the result is the unbreakable entity itself (Figure 3.b). When two edges coming from XPs are merged – one providing a set and the other – an unbreakable Entity, the result of Merge is a set containing both arrivals (Figure 3.c).

The other essential operation from the linguistic model involved in the tree – the Type-shift – is based on a formal definition of a structure of a different nature (non self-inclusiveness of sets) from the structure used here (see Soschen 2006, 2008 for linguistic details).

Let's put the functional representations of the proposed model:

- All Ø are empty sets that enter the treatment to be merged. They are seen as promoters of assembling larger semantic units that corresponds to the observed event;
- Mental images of each entity is first Ø-merged to produce XP (singleton set) ready to participate in the mental construction of a larger unit;
- The obtained after Merge nonempty sets are type-shifted. This corresponds to the creation of a compound with a new meaning - an unbreakable semantic unit;
- The unbreakable units of Entities are merged with empty sets to express that they carry on the route of the mental processing of the phrase meaning.

As defined in linguistics, Merge operates on inputs of different types. This accounts for the Type-shift from sets to entities and from entities to sets. This happens at each step on the paths of merging - up to the root. As a result, at some level, XP is a construct (a set); at another level, it is merged as [X] (unbreakable Entity). Figure 3.d illustrates the consequent changes of the type of the merged 'substance' during the bottom-up processing of the Entities C, D, and E that 'enter' the processing at its bottom level. The basic elements – Entities that enter the tree are first 'transformed' into sets by undergoing a Ø-Merge operation.

The number of the merged Entities

Now let apply the reverse reasoning. There are images of Entities that merge in the context of some action. The action, by assumption, does not yet have a name. The goal is to see what kind of verbs could be mentalized if the rules suggested in linguistics are followed.

Given the rules for processing mental images, based on what is proposed in linguistics and explained above, let us consider how the various numbers of Entities would be processed to be filled into an overall picture of an observed scene. Let us assume that this would engender a mental image of a verb that explains what is happening.

The 'syntactic meaning' of the three in Figure 3.d. as well as of its Fibonacci sub-trees of H=1 and H=2 are shown in Figure 4. When filled with lexical content, the trees are expressed in sentences, e.g., "Mary smiled" for H=1 and e.g. "Mary loves John." for H=2. The three basic structures in English (and a big part of contemporary languages) are as follows: E(R), E(R)E, and E(R)EE.

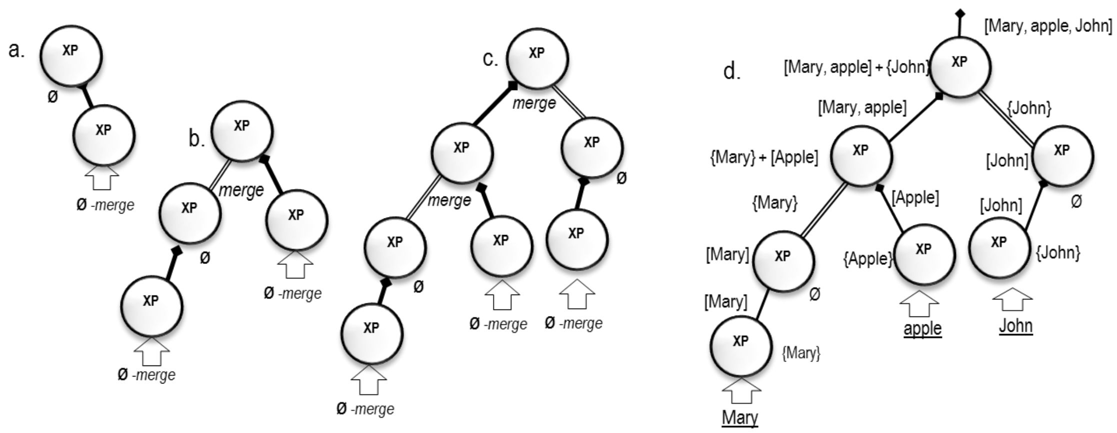


Figure 4. Argument-based trees of different heights. a. H=1 as in "Mary smiled"; b. H=2 as in "Mary loves John"; c. H=3 as in the example in d. "Mary gave John an apple".

When filled with lexical content, these structures appear as SV (Subject-Verb), SVO (Subject–Verb–Object), and SVOR (Subject–Verb–Object–Recipient). These structures correspond clearly to the configurations (of another type) obtained using the linguistic approach in the work of Soschen (2006).

In linguistics, valence is the number and type of arguments controlled by a predicate, verbs being typical predicates. Hence, the merging trees in Figure 4. a, b and c correspond to verbs with valence 1 (walk, smile, etc.) to valence 2 (take, love, etc.) and to valence 3 (give, as in the example in Figure 4.d). Let us stipulate that valence is the number referring only to the required set of arguments that create the mental image of the verb. In this sense, many verbs can take more arguments without them being obligatory. For example, take and love require stating what and are of the second valence, while see can make a meaningful phrase without specifying what. Write can take one, two, or three arguments because Victor writes + letter + Ana can express a complete scene at the end of each of the segments. This is not the case of give (Victor gives + letter + Ana). In most languages give cannot form a phrase without specifying what is given and to whom, the verb is requiring all the three arguments. The guess proposed here is that such verbs arose as a mental image based on mental Merge of three Entities within a single action. One can suppose that once mentally created, the image of the action has been given a name in the language, a verb, and its use requires always its three arguments.

Assume that in some initial moment only the Entities were lexicalized. Let us now see how many Entities can be bound mentally to describe a single action, if indeed the images of Entities are the basis for obtaining the verbs.

From the formal point of view, the explained argument-based syntactic tree is as high as this is specified in its recursive definition and this determines the number of leaves, the Entities, which for a Fibonacci tree are: 1, 2, 3, 5, 8, 13, etc. for H = 1, 2, 3, 4, 5, 6, etc. respectively. But the way of merging lexicalized items has rules that linguists have studied has suggested.

Two types of units participate in the semantic merge – semantic units ready to participate in a larger construction, expressed by singleton sets {} and unbreakable semantic units [].

Let define the rules and the operations more precisely:

- Øμ – Ø-Merge: The mental image E of an Entity becomes ready to participate in the construction of larger meaning-unit – it is "transformed" into the singleton set {E}.

Øμ (<u>*E,*</u> Ø) = {E}

- μ – Merge can be performed only between a set and an unbreakable semantic unit.

The result of Merge is:

  - μ (Ø, [E]) = [E] when merging unbreakable unit with an empty set Ø;
  - μ({E1},[E2])= {E1, E2} when merging unbreakable unit with nonempty set:

- τ – Type-shift – on each step, the mental images obtained after Merge are transformed:

τ ([E]) = {E}

τ ({E}) = [E]

Figure 5.a illustrates the paths of merging of a tree of height H=4 with 5 leaves – the entities A, B, C, D, and E. The Ø-Merge operation transforms the Entities into sets. The further merges and type-shifts for all the involved entities are illustrated in the figure. The edges illustrated with a double line symbolize the movement of a set up to the parent node, and the edges with a single line – the movement of an unbreakable unit. A corresponding recursive procedure reflecting all the enumerated rules is given in Figure 5.b. As shown on the scheme of the tree of height H=4, both edges arriving at the root transmit unbreakable Entities and thus they cannot be merged.

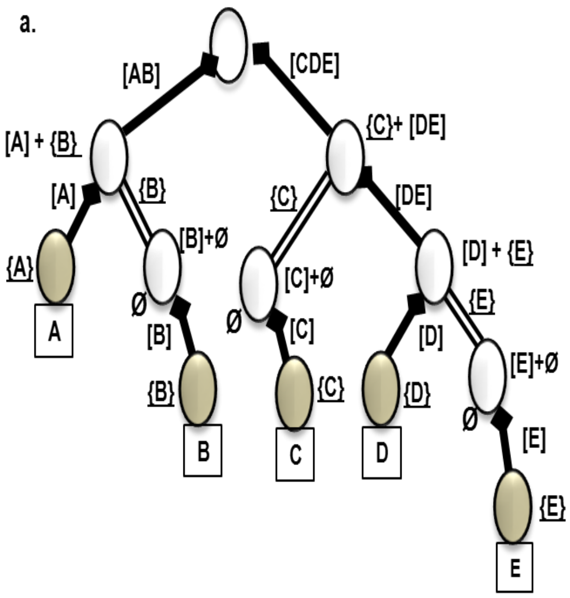
The three of height 4 with 5 participating Entities cannot be merged.

The highest tree that can be merged is this of a height 3, with three Entities involved. Thus when respecting the suggested linguistic rules of Merge and Type-shift, the recursive procedure will allow involving a maximum of three

Entities in the processing. This corresponds to the tree shown in Figure 4.c. and 4.d. The maximum configuration corresponds to the arguments determined in linguistics as subject, recipient, and theme.

The maximum tree configuration is limited to three arguments, e.g., “Mary gave John an apple”.

The tree shown in Figure 4.c. and 4.d. can be called a ‘maximum’ argument-based tree. This tree defines the maximum number of XPs that can be merged in a unique procedural way into a configuration to the root where a meaningful relationship between these XPs is established.



b.

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Processing tree with root – the root
If the node is not empty
   If the node is not a leaf
     LeftBranch = Processing tree with root - left son
     Type-shift
     RightBranch = Processing tree with root - right son
     Type-shift
     Merge (LeftBranch, RightBranch )
   Else
      Ø-Merge to include the Entity (result – {E})
Else return Ø

Merge (LeftIn, RightIn)
Result: Set + Unbreakable = Set
or
Result:  Ø + [E] = [E]
Return Result
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Figure 5.a: Bottom-up processing of semantic merge; b: Formal recursive procedure (pseudo cod)

Discussion

The reasoning on the formal recursive procedure led to the conclusion that if the constraints of the operations Merge and Type-shift are respected, the maximum number of entities that can be merged is three. The proposed processing tree provides a finite, unambiguous, and operational handling of information units that correspond to mental images of Entities. From the formal processing point of view, the constraint on the number comes from the operations Merge and Type-shift.

The question of the height of the tree is also related to the capacity of the working memory to store the intermediate results. How many Entities can be kept during the processing? The fact of a limited procedural recourse is accepted as a principle in cognitive science. It is known that non-human primates can be taught to use Lexigram boards and thus communicate with humans. However, many cognitive scientists believe that they are not proficient in syntax. It is reported that, for example Kanzi – a trained primate – constructs complex phrases using the board by first listing the objects and showing the action at the end of the "phrase". To express the verb he often helps himself with gestures, somehow amalgamating the actions from the board and makes other oddities that inconsistent with the syntax of English he has been listening to since birth (see Savage-Rumbaugh, E. S., & Lewin, R., 1994).

The recursive structuring at the level of language is maybe limited to our species (see Hillert, 2020 for a detailed analysis, sources, and facts). At the same time, as mentioned, not all contemporary languages employ recursion at the level of language. It can be easily shown that the expression of the recursive argument tree at the level of language can become linear. For illustration, the tree on Figure 4.d will be expressed by a linear grammar, without any syntactic categories, for example (Mary), (apple), (John). It could be proposed that the mental image of these three merged Entities creates the representation of the verb “give” when their merged set is transformed to unbreakable, as proposed in the figure. When applying semantic strategies such as Agent-first (see Jackendoff & Wittenberg, 2017), based on rules of word order, the sentence will indicate that Mary is the one who gives, John is the receiver and the object is an apple. The linear surface, especially when the word order is based on strict rules, cannot influence the recursive mental processing assumed here to assign the roles.

The idea was that if, in the initial moment of language development, it was limited to naming Entities, some mental mechanism caused the generation of named mental images for the verbs. Returning to the modern state of the language, verbs have a valence which, if the obligatory number of arguments is taken into account, is most often one, often two, very rarely three and, according to linguistic studies, in some languages there are verbs with a valence of four. If the model based on what linguistics has suggested about Merge and Type-shift is correct, the question arises as to how the image of four-valent verbs arose. Obviously, either the model is based on reasoning only about English, or the structure and way of accounting for valence in languages that have four-valent verbs are different. It has to be noted that in the domain of linguistics the approaches differ. For example, some linguists say that Carnie (see Carnie, 2021) showed that the number of arguments in a thematic domain is necessarily limited to three. Such facts have not found an explanation in linguistics so far. The schemes obtained here correspond clearly to this linguistic point and show a formal procedural reason that explains it.

CONCLUSIONS

The proposed Fibonacci tree model suggests that syntax utilizes recursive calculus to connect arguments and express relations between these arguments. The recursive reasoning alone did not provide a restriction to the number of arguments, that is – to the height of the tree and the number of the Entities that can be merged. The restriction came from the inclusion in the processing model of specific mental operations – Merge and Type-shift. Thus, these proposed operations of mental calculus made it evident that mental processing has procedural limits (Figure 4.a).

The proposed processing tree model assigns a primary syntactic role to Entities. This allowed proposing how the mental images of verbs arose from the initially existing Entity images. It turned out that with the proposed recursive mechanism based on linguistic models, a maximum of three Entities can be linked in an interaction image. Linguistics has the last word, of course.

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