Semiotax: equational models for the linguistic sentence and the 'computational thought'

Francisco José López Quintana

SEMIOTAX:

EQUATIONAL MODELS

FOR

THE LINGUISTIC SENTENCE & THE 'COMPUTATIONAL THOUGHT'[1]

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Abstract

This paper presents several models of equations useful for Natural Language Processing. In this regard, a formal language for the analysis of sentences is used in order to introduce four prototypes of linguistic syncretism derived from the universal sentence equation; afterwards, we adopt another approach to explore the different structures of which every sentence is composed. Eventually, all these processes will lead to the archetypal pattern of what will be called 'computational thought'.

Key Words: sentence equations, computational thought, morpho-functional dimension, configurational dimension, structures

1. Introduction

Throughout the pages of this paper we will put forward the encoding of a sentence by using a formal language within the framework of the so-called *Sentence Semiotax* –henceforth *SS*–,[3] so that all the approaches presented from

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[3] The original in Spanish is *Semiotaxis de la Oración* (*SO*) (López Quintana and López Ramos, 2021: 19).

now onwards will conform to the principles and methodology of the aforementioned linguistic theory.

On the other hand, given the impossibility of finding patterns common to all languages from a formal perspective –i.e. exclusively morphosyntactic–, in spite of the innumerable efforts in that direction –especially on the part of *Generative Grammar* and its ramifications–, it is necessary to introduce a broader vision. Actually, it is possible to combine the lexical-semantic and morphosyntactic levels at another one, called morpho-functional (López Quintana and López Ramos, 2021: 47), where the previous ones can integrate so that they manifest the relations established in every sentence between the verb and its arguments or, more specifically, the relations of the verb –as head of the Vectorial connector (or Vector)– in its interaction not only with the Referential element (or Referent), but also with the Terminal element (or Terminus) (López Quintana and López Ramos, 2021: 19-20).

It should also be noted that in order to carry out the morpho-functional analysis of the sentence, it is first necessary to classify the words of a language into two groups: lexical and grammatical components. Lexical components are those words that can be expanded and, within this group, the following distinction must be drawn: (a) Nominalisers, made up of nouns, pronouns,[4] and adjectives; and (b) Vectorisers, which are verbs.[5] Grammatical components lack this expanding character and are represented by the rest of the words. Adverbs can be placed within both lexical and grammatical components, depending on their functional capacity for expansion (López Quintana and López Ramos, 2021: 247 & ff.).

Consequently, we will aim to explore the analytical potential of the universal equation of the sentence (3),[6] offering not only its methodological development on the morpho-functional level, but also a new dimension that shows a clearer perspective of the double configuration characterising every sentence as a TERNARY STRUCTURE, whose elements can

[4] Pronouns are usually classified as grammatical words; however, for *SS* –in line with other scholars who regard them as a subclass within nouns (Huddleston and Pullum, 2002: 425; Aarts, 2011: 29)–, they belong to the group of lexical components because they have the capacity for expansion, unlike grammatical components, which lack it (López Quintana and López Ramos, 2021: 248-249).

[5] Verbs in the infinitive form (and in English also gerunds) will, in certain cases, be Nominalisers.

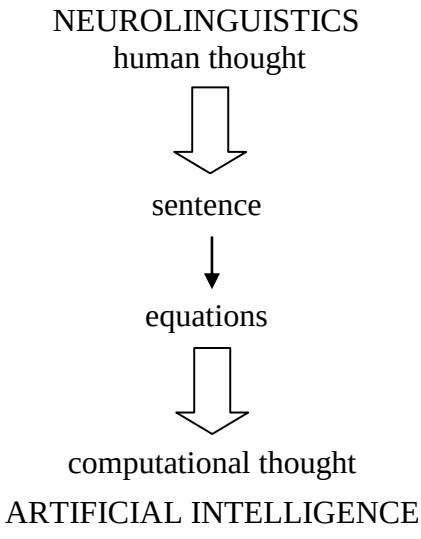
[6] Linguistics shares with the Human Sciences, such as Philosophy, the abstract aspect –and therefore more imprecise– related to the level of content of language, but it also bears evident similarities with the Experimental Sciences, such as Physics or Chemistry, in its material aspect –and therefore more concrete– regarding the level of expression, which has made it possible to develop mathematical modelling applied to grammar during the last decades. However, it would be a mistake to try to leave aside either of the two aspects, since the interrelation between them must be considered when dealing with a field –yet unexplored in depth– such as that of the formulation of equations like those presented here. Thus, when we have (i), we can say that the sentence has a beginning (*Robert*) and an end (*yesterday*) from the formal point of view, but the analysis would be incorrect if we do not take into account the functional perspective, which enables us to state that the terminal element at the morpho-functional level, where the argument-verb relations (López Quintana and López Ramos, 2021: 19 & ff.) are established, is *the article*. And this methodology helps us to formulate equations of the type (2) to finally arrive at (3), known as the equation in the morpho-functional dimension or the universal equation of the sentence (López Quintana and López Ramos, 2021: 246).

(i) *Robert translated the article yesterday*.

be expanded as BINARY STRUCTURES (López Quintana and López Ramos, 2021: 247 & ff.).

Finally, these morpho-functional and configurational dimensions will enable us to set out what can be defined as 'computational thought' by means of different equations which constitute the bridge between the field of neurolinguistics and that of artificial intelligence. In fact, when we speak of 'computational thought', we are referring to the intellectual process –with certain specific features– generated in the human mind ('thought'), and which, at the same time, behaves according to a given algorithm ('computational'). However, it would be risky to state, without conclusive and definitive evidence –despite the arguments offered by the *Computational Theory of Mind*–, that every human thought functions computationally; nevertheless, there is no doubt that it is always feasible to express any thought algorithmically –regardless of whether or not it has been generated in that way– by means of a sentence. For this purpose, we will start from the following postulate: if we define a thought as the relationship set up between two ideas and we regard a sentence as the expression of a thought,[7] then every sentence has to be made up of three parts (an initial element, a final one and a connector) in order to perform the transmission of sense from a concept to another notion by means of a third one. In this way, the characteristic of *transitivity* becomes the linguistic attribute that turns a group of words into a TERNARY STRUCTURE, i.e. a sentence (López Quintana and López Ramos, 2021: 45), which can be represented with accurate equations. Thus, we would have: (1).

(1)



[7] It is important to underline that we are not addressing here the issue of the nature of thought, which is a subject of much debate. However, since one of our focus of interest lies in encoding ideas, we must previously transform thought into an easily manageable tool like a sentence as the only way to process it by using a formal language. Consequently, in this paper the relation between thought and language is envisaged as a methodological need and not as a debatable point.

2. Sentence equation in the morpho-functional dimension: prototypical models of syncretism

According to *SS*, every sentence consists of a Referential element (α), a Vectorial connector (V), and a Terminal element (ω) as basic and essential items; but optionally there could also be an indeterminate number of Adjunct (A) and Circumstance elements[8] (©) –as we will exemplify below–, so that we would arrive at equation (2), which turns into (3) if we refer to the argument poles (α and ω) as *p*. Therefore, (3) becomes the equation of the morpho-functional dimension or the universal equation of the sentence (López Quintana and López Ramos, 2021: 246).

(2) $S_0 = mA + \alpha + V + \omega + n©$ ($m, n \geq 0$).

(3) $S_1 = mA + 2p + V + n©$ ($m, n \geq 0$).

Now, we will show an example of the type of analysis obtained by applying the above equations derived from the semiotaxic[9] assumptions; for this purpose, we will examine a complex sentence in which there is a subordinate clause of circumstance.

(4.1) *My friends were able to visit India after they had made enough money in a casino.*

(4.2)

My friends	*were able to visit*	*India*	*after they had made enough money in a casino.*
α	V	ω	©

(4.3)

My	*friends*	*were able to*	*visit*	*India*[10]	…
α_0.a	α_0	V_0.a	V_0	ω_0	

[©]:[11] [*after they had made enough money in a casino*.]

…	*after*	*they*	*had made*	*enough*	*money*	*in*	*a*	*casino.*
	[©].a	[©]α	[©]V	[©]ω_0.a	[©]ω_0	[©]$©_0$.a	[©]$©_0$.b	[©]$©_0$

Then:

[8] These Adjunct and Circumstance elements are non-arguments and consequently optional (López Quintana and López Ramos, 2021: 246).

[9] We prefer the use of this term to 'semiotactic'.

[10] The lexical items are: α_0, α_1, $\alpha_{2...}$, V_0, and ω_0, ω_1, $\omega_{2...}$; the matrix lexical items (i.e. heads) have a subscript 0: α_0, V_0, and ω_0; while the additional lexical items (i.e. non-heads) have a subscript other than 0: α_1, α_2...; ω_1, ω_2... The grammatical items are represented by the lexical item on which they depend followed by a dot and a letter of the English alphabet: α_0.a, α_0.b...; α_1.a, α_1.b...; V_0.a, V_0.b...; ω_0.a, ω_0.b...; ω_1.a, ω_1.b... (López Quintana and López Ramos, 2021: 256).

[11] The square bracket enclosing the symbol © means that it is a subordinate clause which performs the morpho-function of a Circumstance element. It will appear before every item which makes up this Circumstance element as can be seen in the detailed analysis which follows. The symbol © inside the square bracket followed by a dot and a letter of the English alphabet ([©].a) –as can be seen with the word *after*– indicates that it is an introductory nexus of the subordinate clause.

(4.4) $S = \alpha_0.a + \alpha_0 + V_0.a + V_0 + \omega_0 + [©]$

$[©].a + [©]\alpha + [©]V + [©]\omega_0.a + [©]\omega_0 + [©]©_0.a + [©]©_0.b + [©]©_0$

Likewise, we may sometimes find a complex Vectorial connector such as in (5). In this situation, if we want to recognise the universal equation (3) there, we can look up the word *hand out* in a dictionary like, for instance, the *Oxford Advanced Learner's Dictionary of current English (OALD)*, where we observe that it shows the following structure: "hand something out (to somebody)" –therefore, with two arguments, one compulsory: "something", and another optional: "to somebody"– with this definition: "to give a number of things to the members of a group" (*OALD*, 1995). Once we have recognised *yesterday* as a Circumstance element –for its meaning of temporality– and that *the company* is the Referential element (or Referent) –as the morphosyntactic and lexical-semantic Reference–[12], we need to classify the groups *the award* and *to its manager* appropriately. The first element is the one that characterises the transitivity of the verb (syntactic level) and, thus, the one compulsorily present in its structure. The second element also has an argument feature,[13] although this does not imply that it always has to appear explicitly, unlike the first one (6). Certainly, a sentence like (7) would be incorrect because of the absence of its Direct Object. If we now use the parameters related to the PRINCIPLE OF TERNARY STRUCTURE underlying every sentence (López Quintana and López Ramos, 2021: 165 & ff.), we will identify the group *to its manager* as the Terminal Element (or Terminus) and *the award* as a Nuclear supplement included within the Vectorial connector (or Vector), which has *handed out* as its head:[14] (8) and (9).

(5) *The company handed out the award to its manager yesterday.*

(6) *The company handed out the award to its manager yesterday.*

(7) **The company handed out to its manager.*

(8) *The company* <u>*handed out*</u> <u>*the award*</u> *to its manager yesterday.*

<u>Vectorial head</u> <u>Nuclear supplement</u>

Vectorial connector

[12] The morphosyntactic and lexical-semantic References (also called Subject and Resema) make up the Referent or Referential element (López Quintana and López Ramos, 2021: 91 & ff.).

[13] It would be highly pertinent to examine the role that dictionaries must play in the linguistic and computational analysis of sentences if a truly scientific study is to be carried out, i.e. without depending on the speakers' subjectivity of a specific language. However, due to its complexity, this issue will be dealt with in another article.

[14] It is impossible to explain here the reasons why the Vectorial connector consists of the group *handed out the award* from the point of view of the *SS*; for this, see López Quintana and López Ramos (2021: 108 & ff.). Suffice it to say, at least, that –in this case– the reason why this structure constitutes a morpho-functional unit is linked to its similarity of meaning with the verb *awarded*.

(9) *The company* *handed out the award* *to its manager* *yesterday*.
Referential element Vectorial connector Terminal element Circumstance element
α V ω ©

The universal equation in its form (2) allows us to continue developing new equational models that facilitate the expression of the sentence sequence in a formal language by means of the following four prototypical models of syncretism: an intransitive sentence (10.1), a sentence in which the Referential element is included in the Vectorial connector (11.1), a sentence with absence of verb (12.1), and an intransitive sentence without an explicit Referential element (13.1):

- In (10.1) we have the Terminal element combined with the Referential element.

(10.1) *The tree* *grew*.
α = ω V

(10.2) S = α + V + ω

(10.3) α = ω ⟶ ω = ε; S = α + V + ε. *The tree grew*.
α + V + ε

(10.4) α + ε = $α_ε$; **S = $α_ε$ + V**. *The tree* *grew*.
$α_ε$ **V**

[ε: *ensamblaje*] ['blending'][15]

- Now we will see the formal expression of a sentence where the Referential element (*you*) is not shown as an independent word (11.1), but joined to the Vectorial connector (*close[-Ø]*).

(11.1) *Close* *the cupboard*.
α ⊂V ω

(11.2) S = α + V + ω

(11.3) α ⊂V ⟶ α = φ; S = φ + V + ω. *Close the cupboard*.
φ + V + ω

(11.4) φ + V = $V_φ$; **S = $V_φ$ + ω**. *Close* *the cupboard*.
$V_φ$ **ω**

[φ: *fusión*] ['merging']

- Another form of syncretism is found when the Vectorial connector is explicitly absent:[16] (12.1).

[15] The Greek letters ε, φ, ι, and σ correspond to the initials of the Spanish words: *ensamblaje*, *fusión*, *integración*, and *síntesis*.

[16] When the Vectorial connector is left out (usually a copulative verb), it is considered to have been taken in by the Terminal element, leaving a comma as a meaningful mark of its implicit presence (López Quintana and López Ramos, 2021: 168 & 177).

(12.1) *Jason, a fool.* [Jason *(is) a fool*.]

(12.2) S = α + V + ω

(12.3) V ⊂ ω ⟶ V = ι; S = α + ι + ω. *Jason, a fool.*
α + ι + ω

(12.4) ι + ω = ω_ι; **S = α + $\boldsymbol{\omega_\iota}$.** *Jason*, *a fool.*
α **$\boldsymbol{\omega_\iota}$**

[ι: *integración*] ['integration']

- Finally we will show the most intense syncretism that appears when both the Referential element (*you*) and the Terminal one (*you*) are blended and incorporated into the Vectorial connector:[17] (13.1).

(13.1) *Come!*
α ⊂ V; ω = α

(13.2) S = α + V + ω

(13.3) α ⊂ V ⟶ α = φ; ω = α ⟶ ω = ε; S = φ + V + ε. *Come!*
φ + V + ε

(13.4) φ + ε = σ; σ + V = V_σ; **S = $\mathbf{V_\sigma}$.** *Come!*
$\mathbf{V_\sigma}$

[σ: *síntesis*] ['synthesis']

3. Sentence equation in the configurational dimension

In this section we will aim at exploring a new dimension of the sentence equation through the configurational levels that every sentence displays such as it has been put forth in *SS* (López Quintana and López Ramos, 2021: 247 & ff.):

1st Configuration: it corresponds to the Sentence. It is distinguished when a TERNARY STRUCTURE, made up of three essential Sentence Segments, can be identified: the Referential element, the Vectorial connector, and the Terminal element; in addition, there may be other optional elements such as Circumstance elements (and Adjunct elements).

2nd Configuration: it corresponds to the composition of the above-mentioned Sentence Segments, whose elements can be expanded by means of a BINARY STRUCTURE.

[17] For a detailed explanation of this syncretism, see López Quintana and López Ramos (2021: 121-122).

However, we will now add (to the 1st Configuration) what we will call the SINGULAR STRUCTURE, related to the optional Circumstance elements (and Adjunct elements). Therefore, we will establish (14) as the equation of the sentence structure (S_2) or the equation in the configurational dimension.

(14) $S_2 = \tau + m\gamma + n\beta$ ($m, n \geq 0$).

And in (14) we have to define the following elements:

(a) S_2 = equation of the sentence structure.

(b) τ is the representation of the compulsory TERNARY STRUCTURE. Furthermore, $\tau = 3l_{f0}$, where l_{f0} is the lexical matrix (head) of every essential element of the sentence, called 'funseme'[18] (López Quintana and López Ramos, 2021: 78), which can be: Referential element, Vectorial connector, and Terminal element. When some kind of the aforementioned syncretism appears, we must operate as follows: $\tau = 3l_{f0} - 1$ for (10.1), (11.1), and (12.1), while $\tau = 3l_{f0} - 2$ for (13.1).[19]

(c) γ symbolises the optional SINGULAR STRUCTURE of every Circumstance element (and also of every Adjunct element). Therefore, $m\gamma$ will be the number of Circumstance elements (and Adjunct elements) in a sentence, which corresponds exactly to the number of their lexical matrix elements (heads). So $m\gamma = ml_{\gamma 0}$, where $l_{\gamma 0}$ is the lexical matrix (head) of every Circumstance element (or Adjunct element) and $m \geq 0$.

(d) β indicates the optional BINARY STRUCTURE present in both the TERNARY STRUCTURE and the SINGULAR STRUCTURE. Hence, $n\beta$ will be the number of BINARY STRUCTURES in a sentence, identical to the number of additional (non-matrix or non-nuclear) elements in those TERNARY and SINGULAR STRUCTURES. Thus, $n\beta = nl_{á}$, where $l_{á}$ is the additional (non-matrix or non-nuclear) element, where $n \geq 0$.

Then, we can draw the conclusion that, from (14), the sum total of the lexical items in a sentence (S_l) would be expressed as follows: (15).

(15) $S_l = 3l_{f0} + ml_{\gamma 0} + nl_{á}$ ($m, n \geq 0$).

Next, we will use equation (15) to analyse sentence (16) in order to observe the correlation between the number of its lexical items and the structures of which it is made up.

(16) *Some Spanish fishermen from the boat run aground on the sand set up tents on the eastern beach at the beginning of July*.

Thus, we find:

[18] Hence, the subscript f in $3l_{f0}$; the subscript 0 indicates that it is a matrix (head), as noted above.

[19] In these situations the ternary structure persists; however, the number of lexical units is different, since one of them incorporates the others into itself.

(a) τ = $3l_{τ0}$, i.e. τ = *fishermen, set up,* and *tents*; there is only one TERNARY STRUCTURE with three matrices (heads) of essential elements: Referential element (*fishermen*), Vectorial connector (*set up*), and Terminal element (*tents*).

(b) *m*γ = $ml_{γ0}$, i.e. $2l_{γ0}$ = *beach* and *beginning*; $2l_{γ0}$ = 2γ, so we have two SINGULAR STRUCTURES, since we have identified two matrices (heads) corresponding to two Circumstance elements.

(c) *n*β = $nl_{á}$, i.e. $7l_{á}$ = *Spanish*, *boat*, *run aground*, *sand*, *eastern*, *month*, and *July*. Therefore, $7l_{á}$ = 7β, which indicates that, since there are seven additional (non-matrix or non-nuclear) lexical elements, we will consequently have seven BINARY STRUCTURES.

In short, we obtain (17), where –by applying (15) from (14)– we can see the structural organisation (ternary, singular, and binary) which gives the final result of twelve lexical items in the sentence. It is clear that the same number of lexical items could be obtained when having a different distribution of structures, so the relevance of the equation lies, above all, in allowing us to appreciate the type of organisational schema shown by any sentence sequence.

(17) S_2 = τ + *m*γ + *n*β ⟶ $S_{ι}$ = $3l_{τ0}$ + $ml_{γ0}$ + $nl_{á}$ = $3l_{τ0}$ + $2l_{γ0}$ + $7l_{á}$ = 12.

We must bear in mind that in the context of the *SS* applied to Natural Language Processing we encode every sentence into an integer format[20] taking into account only lexical words,[21] which convey the basic meaning of the sentence in the two configurational dimensions we have already examined:

(a) 1st Configuration: it just considers matrix elements.

(b) 2nd Configuration: it specifies the sense of the matrix by means of lexical non-matrix elements.

Then, for sentence (16) we have the following 'vectorisations':

V = {at, beach, beginning, boat, eastern, fishermen, from, July, of, on, run aground, sand, set up, some, Spanish, tents, that, the}

(a) 1st Configuration:

(0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 1, 0, 0, 1, 0, 0)

(b) 2nd Configuration:

(0, 1, 1, 1, 1, 0, 0, 1, 0, 0, 1, 1, 0, 0, 1, 0, 0, 0)

[20] 'Vectorisation' or 'word embedding'.

[21] It is specially useful when dealing with translation because it displays a global perspective of the meaning of a sentence leaving aside structural aspects of language.

However, it is obvious that the descriptive scope of the above equation has certain limitations, so it is essential to show –by means of some illustrative graphs– a more detailed analysis of both the organisation and the variations that can take place in the above-mentioned structures. For this purpose, we will use the following examples: (18), (19), (20), (21), and (22).

(18) *Sheila's red pen* *is in the drawer.*
α

(19) *We have lost Sheila's red pen.*
ω

(20) *An accident took place on the unlit narrow street.*
γ

(21) *The army inflicted a humiliating defeat on the enemy.*
V

(22) *The boy delivered a resounding slap to his brother.*
V

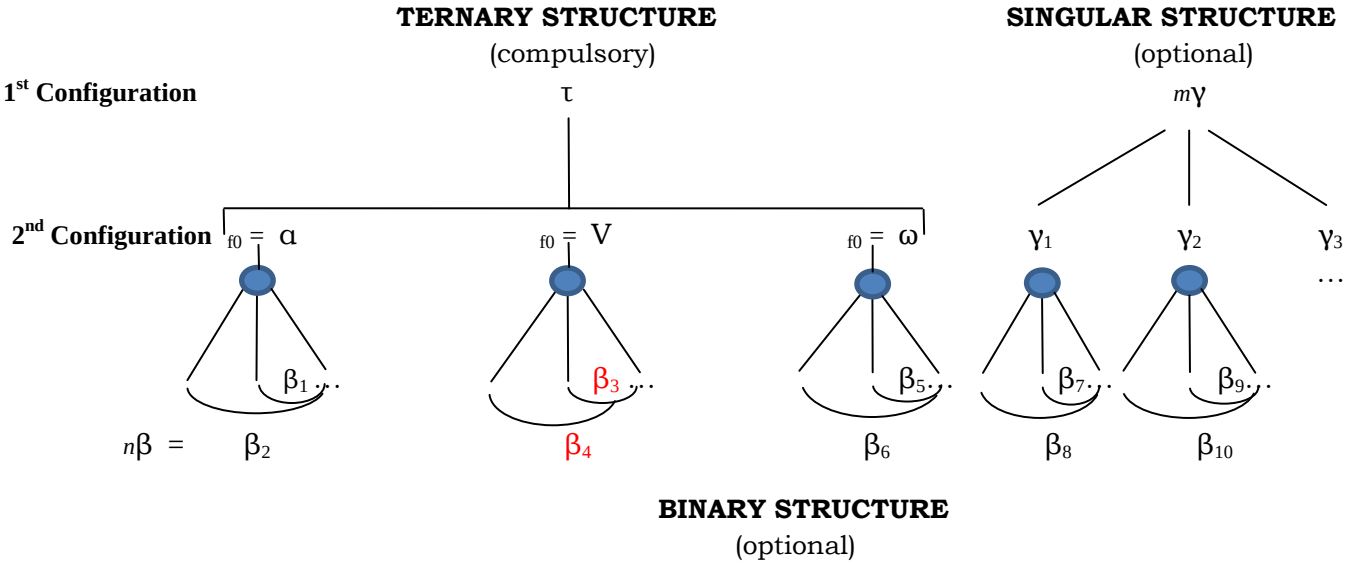


Figure 1: Type 1 of multilevel structure.

(23)

- α / ω = *Sheila ['s] red pen.*

  β1 / β5) *red pen.*

  β2 / β6) *Sheila ['s] pen.*

  ○ *Sheila ['s] red pen.*

(24)

- V = *inflicted [a] humiliating defeat*.[22]

  - *inflicted*.

  β_3) *[a] humiliating defeat*.

  } β_4) *inflicted [a] humiliating defeat*.

(25)

- γ_1 = *[on the] unlit narrow street*.

  β_7) *[on the] narrow street*.

  β_8) *[on the] unlit street*.

  } ○ *[on the] unlit narrow street*.

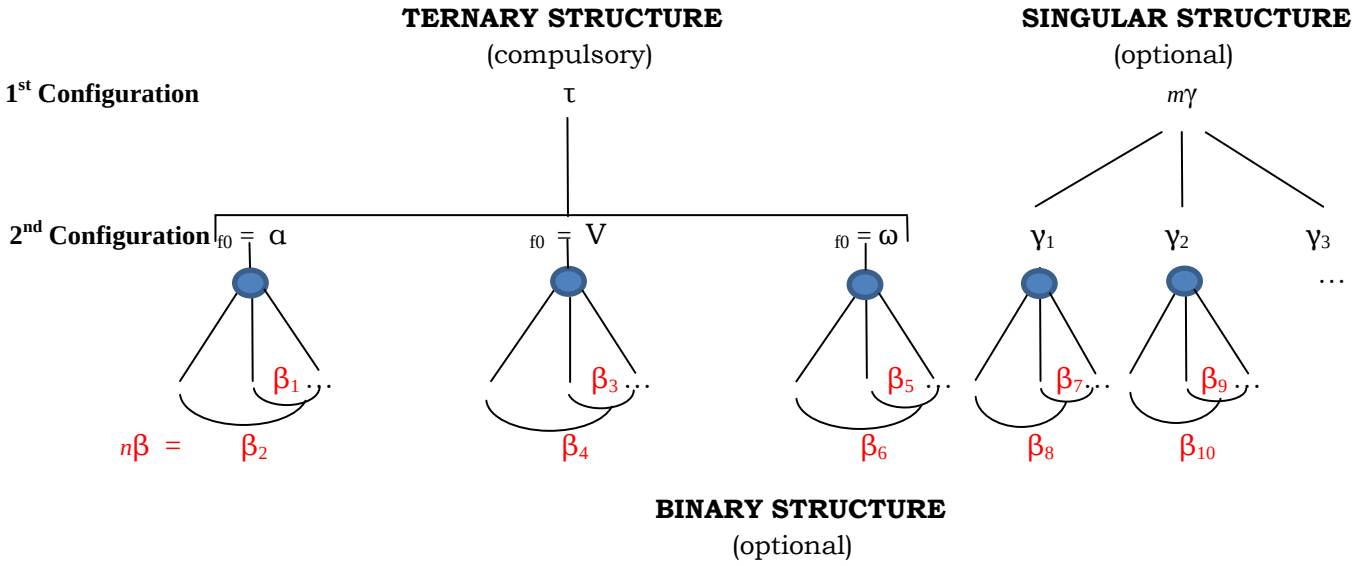


Figure 2: Type 2 of multilevel structure.

[22] As we saw in footnote 14, we can't explain here the reasons why *a humiliating defeat* is included in the Vectorial connector together with *inflicted;* for this, see López Quintana and López Ramos (2021: 108 & ff.). At least, the similarity between *inflicted a defeat* and the verb *defeated* can provide the justification to consider the former group (made up of the verb and the nominal group) as a functional unit. In the same way, we will see below that the group *delivered a resounding slap* is the Vectorial connector since it constitutes a functional unit: here we can also notice the similarity of meaning between *delivered a slap* and the verb *slapped*.

(26)

- α / ω = *Sheila ['s] red pen.*
  - *Sheila ['s].*
  - β_1 / β_5) *red pen.*

  } β_2 / β_6) *Sheila ['s] red pen.*

(27)

- V = *delivered [a] resounding snap.*
  - *delivered.*
  - β_3) *[a] resounding slap.*

  } β_4) *delivered [a] resounding slap.*

(28)

- γ_1 = *[on the] unlit narrow street.*
  - *unlit.*
  - β_7) *[on the] narrow street.*

  } β_8) *[on the] unlit narrow street.*

Therefore, we have β ⊂ τ, but also β ⊂ γ in both figures.

The crucial issue in the former examples has to do with the different BINARY STRUCTURES which should convey a difference in meaning. In this regard, we will interpret them according to the convention established in López Quintana and López Ramos (2021: 256-257). As far as α / ω are concerned, structure (23) (Figure 1) corresponds to the case where there is only one pen which is red and belongs to Sheila, while (26) (Figure 2) represents the situation where there are several red pens but the phrase is referring to the one which belongs to Sheila. Similarly with γ_1: (25) (Figure 1) indicates that there is only one street which is narrow and unlit, as opposed to (28) (Figure 2), where there are several narrow streets but the reference is made to the one which is unlit.

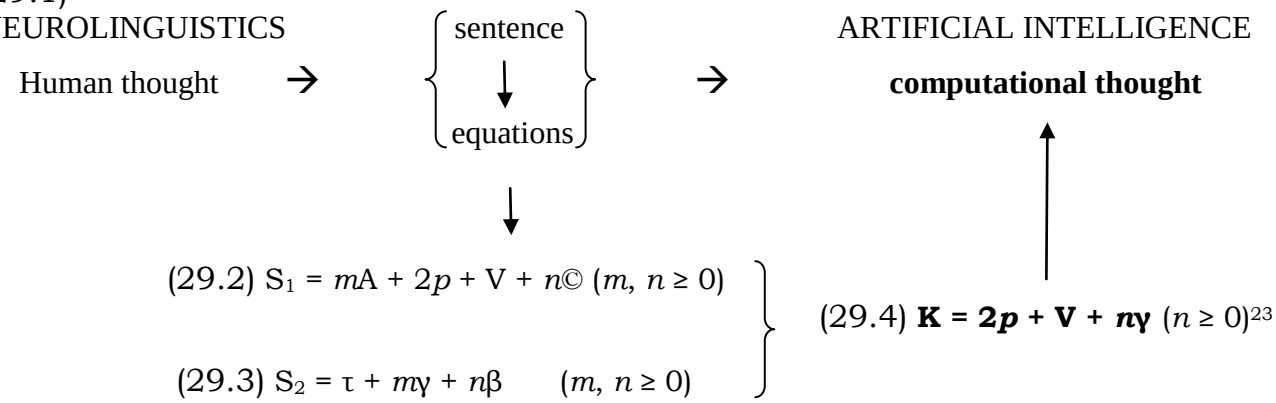
Moreover, it is necessary to distinguish in the Vectorial connector between the verb group (Vectoriser), on the one hand, and the noun and adjective groups (Nominalisers), on the other, before proceeding to the determination of the BINARY STRUCTURES. Therefore, the structure β of V in (24) (Figure 1) appears in red to show that it is different from the rest of the nodes in that group; actually, its structure is identical to (27) (Figure 2). Thus, in (24), we will have,

first, *[a] humiliating defeat* as a binary structure with the lexical elements of the noun and adjective groups (Nominalisers) and, afterwards, the union of the lexical item in the verb group (Vectoriser): *inflicted* with the previous structure, giving as a result the phrase *inflicted [a] humiliating defeat*. Likewise, in (27), first, we have the binary structure with the lexical elements of the noun and adjective groups (Nominalisers): *[a] resounding slap* and, then, the lexical item in the verb group (Vectoriser): *delivered* plus the former structure, which results in *delivered [a] resounding slap*.

4. Equation of 'computational thought'

As a result of the aforementioned equations, we could give a more detailed explanation of (1) in the following way:

(29.1)



Equation (29.4) derives from equations (29.2) and (29.3). It is made up of three elements so as to formulate the 'computational thought' or 'coneme'[24] symbolised by K: two of them taken from S_1 ($2p$ + V), and another one from S_2 ($m\gamma$). Each of these units (belonging to every 'coneme') is called 'axeme';[25] they can be classified into two different kinds:

[23] We must take into account that, in equation (29.2), the symbol A corresponds to Adjunct items and © to Circumstance elements (López Quintana and López Ramos, 2021: 246, footnote 6). Nevertheless, in (29.4) both are represented with the symbol γ taken from equation (29.3), so the linguistic feature disappears in the 'computational thought' (29.4). Although in López Quintana and López Ramos (2021: 279) it was stated that equation (29.2) could also stand for the 'computational thought', it is necessary to make a formal distinction between the linguistic and the computational fields since the latter reaches a more abstract plane than the former and, therefore, has to be regarded as different.

[24] From the adjective 'computational' and the noun 'noeme' (Greek origin): 'thought'.

[25] They belong to a cognitive-linguistic plane (López Quintana and López Ramos, 2021: 49 & ff.).

(a) Essential 'axemes': they are compulsory elements (from S_1) corresponding to the initial and final poles of every 'coneme', represented by 2*p*, and the Vector, represented by V, which connects them.[26]

(b) Optional 'axemes': these optional units (from S_2) are represented by γ and integrate Adjunct items and Circumstance elements (from the morpho-functional level of Linguistics).

Moreover, every 'axeme' is made up of two types of subunits:

- A 'matrix subaxeme', which is a suitable representative of its 'axeme' because it bears the main notional load. It corresponds to nuclear lexical elements in linguistic analysis.
- Optional 'non-matrix subaxemes'. They are non-essential notional items. They correspond to non-nuclear lexical elements in Linguistics.

It is important to underline that equation (29.4) can be formulated once we have carried out the morpho-functional and configurational analysis through equations (29.2) and (29.3) in order to enable the transition towards the field of 'computational thought' as we can see below:

(30) *My injured leg hurts.*

(a) Sentence equation in the morpho-functional dimension:

- $\mathbf{S_0 = mA + a + V + \omega + n©}$; $S_{0(30)} = a + V + \omega$
- $S_{0(30)} = a_{\varepsilon 0}.a + a_{\varepsilon 1} + a_{\varepsilon 0} + V_0$

$a_{\varepsilon 0}.a$ = *my*

$a_{\varepsilon 1}$ = *injured*

$a_{\varepsilon 0}$ = *leg*

V_0 = *hurts*

[$\mathbf{S_1 = mA + 2p + V + n©}$ ($m, n \geq 0$); $S_{1(30)} = 2p + V$]

[26] Obviously, the compulsory presence of the poles in a 'coneme' is determined linguistically, i. e. by the semantic level of the words which conveys the 'computational thought' and, thus, is related to the structural rules of a lexical database (like, for instance, a dictionary). When we encode the items of a sentence according to a computational model or formula with a universal scope we can convert it into a 'computational thought'.

(b) Sentence equation in the configurational dimension:

- **$S_2 = \tau + m\gamma + n\beta$** ($m, n \geq 0$)
- $S_{2(30)} = \tau + \beta$

τ = *injured leg* / *injured leg* / *hurts*

β = *injured leg*

(c) Equation of 'computational thought':

- **$K = 2p + V + n\gamma$** ($n \geq 0$)
- $K_{(30)} = 2p + V$

p_1 = "[1st person sing.] injured leg"

p_2 = "[1st person sing.] injured leg"

'matrix subaxeme' = "[1st person sing.] leg"

'non-matrix subaxeme' = "injured"

$p_1 = p_2$

V = "to hurt"

Although *prima facie* lexical elements like, for instance, *injured leg*, in (30)(b), and 'axemes' in (30)(c), e.g. "[1st person sing.] injured leg", seem to be similar, there is a crucial difference. In (30)(b), *injured leg* are lexical words written in italics because they are extracted verbatim from the sentence, leaving aside the grammatical element *my*. Nonetheless, in (30)(c), "[1st person sing.] injured leg" are written between inverted commas and they include the sense conveyed by the possessive determiner *my* since they are 'axemes' representing in an abstract way all the semantic traits transmitted by the linguistic expression: *my injured leg*, i.e. "speaker's wounded lower limb" (see López Quintana and López Ramos, 2021: 50 & 51).

(31) *Me duele la pierna herida.*

(a) Sentence equation in the morpho-functional dimension:

- **$S_0 = mA + \alpha + V + \omega + n$©**; $S_{0(31)} = \alpha + V + \omega$
- $S_{0(31)} = \omega_0 + V_0 + \alpha_0.a + \alpha_0 + \alpha_1$

ω_0 = *me* ('me')

V_0 = *duele* ('hurts')

$\alpha_0.a$ = *la* ('the')

α_0 = *pierna* ('leg')

α_1 = *herida* ('injured')

[$\mathbf{S_1 = mA + 2p + V + n©}$ (m, $n \geq 0$); $S_{1(31)} = 2p + V$]

(b) Sentence equation in the configurational dimension:

- $\mathbf{S_2 = \tau + m\gamma + n\beta}$ (m, $n \geq 0$)
- $S_{2(31)} = \tau + \beta$

τ = *me* ('me') / *duele* ('hurts') / *pierna herida* ('injured leg')

β = *pierna herida* ('injured leg')

(c) Equation of 'computational thought':

- $\mathbf{K = 2p + V + n\gamma}$ ($n \geq 0$)
- $K_{(31)} = 2p + V$

p_1 = "[1st person sing.] pierna herida" ('[1st person sing.] injured leg')

'matrix subaxeme' = "pierna" ('[1st person sing.] leg')

'non-matrix subaxeme' = "herida" ('injured')

p_2 = "yo" ('I')

$p_1 \neq p_2$

V = "doler" ('to hurt')

(32) *J'ai mal à la jambe blessée.*

(a) Sentence equation in the morpho-functional dimension:

- **S_0 = *m*A + α + V + ω + *n*©**; $S_{0(32)}$ = α + V + ω + ©
- $S_{0(32)} = \alpha_0 + V_0 + \omega_0 + ©_0.a + ©_0.b + ©_0 + ©_1$

α_0 = *j(e)* ('I')

V_0 = *ai* ('have')

ω_0 = *mal* ('pain')

$©_0.a$ = *à* ('in')

$©_0.b$ = *la* ('the')

$©_0$ = *jambe* ('leg')

$©_1$ = *blessée* ('injured')

[**S_1 = *m*A + 2*p* + V + *n*©** ($m, n \geq 0$); $S_{1(32)} = 2p + V + ©$]

(b) Sentence equation in the configurational dimension:

- **S_2 = τ + *m*γ + *n*β** ($m, n \geq 0$)
- $S_{2(32)} = \tau + \gamma + \beta$

τ = *j(e)* ('I') / *ai* ('have') / *mal* ('pain')

γ = *jambe blessée* ('injured leg')

β = *jambe blessée* ('injured leg')

(c) Equation of 'computational thought':

- **K = 2*p* + V + *n*γ** ($n \geq 0$)
- $K_{(32)} = 2p + V + \gamma$

p_1 = "j(e)" ('I')

p_2 = "mal" ('pain')

$p_1 \neq p_2$

V = "avoir" ('to have')

γ = "jambe blessée" ('injured leg')

'matrix subaxeme' = "jambe" ('leg')

'non-matrix subaxeme' = "blessée" ('injured')

Let's now compare the following examples to display the processing economy range not only for the linguistic sentence but also for the 'computational thought':

(33) *Il a mal à la jambe blessée.*

(1) Sentence equation in the morpho-functional dimension:

- **S_0 = *m*A + α + V + ω + *n*©**; $S_{0(33)}$ = α + V + ω + ©
- $S_{0(33)} = \alpha_0 + V_0 + \omega_0 + ©_0.a + ©_0.b + ©_0 + ©_1$ → **7 elements**

α_0 = *il* ('he')

V_0 = *a* ('has')

ω_0 = *mal* ('pain')

$©_0.a$ = *à* ('in')

$©_0.b$ = *la* ('the')

$©_0$ = *jambe* ('leg')

$©_1$ = *blessée* ('injured')

[**S_1 = *m*A + 2*p* + V + *n*©** ($m, n \geq 0$); $S_{1(33)} = 2p + V + ©$]

(2) Equation of 'computational thought':

- **K = 2*p* + V + *n*γ** ($n \geq 0$)
- $K_{(33)} = 2p + V + \gamma$ → **4 elements**

p_1 = "il" ('he')

p_2 = "mal" ('pain')

$p_1 \neq p_2$

V = "avoir" ('to have')

γ = "jambe blessée" ('injured leg')

'matrix subaxeme' = "jambe" ('leg')

'non-matrix subaxeme' = "blessée" ('injured')

(34) *His injured leg causes him pain.*

(1) Sentence equation in the morpho-functional dimension:

- **S_0 = *m*A + α + V + ω + *n*©**; $S_{0(34)}$ = α + V + ω + ©
- $S_{0(34)} = \alpha_0.a + \alpha_1 + \alpha_0 + V_0 + ©_0 + \omega_0$ → **6 elements**

$\alpha_0.a$ = *his*

α_1 = *injured*

α_0 = *leg*

V_0 = *causes*

$©_0$ = *him*[27]

ω_0 = *pain*

[**S_1 = *m*A + 2*p* + V + *n*©** ($m, n \geq 0$); $S_{1(34)} = 2p + V + ©$]

(2) Equation of 'computational thought':

- **K = 2*p* + V + *n*γ** ($n \geq 0$)
- $K_{(34)} = 2p + V + \gamma$ → **4 elements**

p_1 = "[3rd person sing.] injured leg"

p_2 = "pain"

$p_1 \neq p_2$

'matrix subaxeme' = "[3rd person sing.] leg"

'non-matrix subaxeme' = "injured"

V = "to cause"

γ = "me"

[27] The pronoun *him* is a non-argument item (referring to the concerned person) and, then, it is regarded as a Circumstance element in *SS* (López Quintana and López Ramos, 2021: 115, footnote 145).

(35) *Le duele la pierna herida.*

(1) Sentence equation in the morpho-functional dimension:

- **S_0 = *m*A + α + V + ω + *n*©**; $S_{0(35)}$ = α + V + ω
- $S_{0(35)} = \omega_0 + V_0 + \alpha_0.a + \alpha_0 + \alpha_1$ → **5 elements**

ω_0 = *le* ('le')

V_0 = *duele* ('hurts')

$\alpha_0.a$ = *la* ('the')

α_0 = *pierna* ('injured')

α_1 = *herida* ('leg')

[**S_1 = *m*A + 2*p* + V + *n*©** ($m, n \geq 0$); $S_{1(35)} = 2p + V$]

(2) Equation of 'computational thought':

- **K = 2*p* + V + *n*γ** ($n \geq 0$)
- $K_{(35)} = 2p + V$ → **3 elements**

p_1 = "pierna herida" ('injured leg')

'matrix subaxeme' = "pierna" ('leg')

'non-matrix subaxeme' = "herida" ('injured')

p_2 = "le" ('him')

$p_1 \neq p_2$

V = "doler" ('to hurt')

(36) *His injured leg hurts.*

(1) Sentence equation in the morpho-functional dimension:

- **S_0 = *m*A + α + V + ω + *n*©**; $S_{0(36)}$ = α + V + ω
- $S_{0(36)} = \alpha_{\varepsilon 0}.a + \alpha_{\varepsilon 1} + \alpha_{\varepsilon 0} + V_0$ → **4 elements**

$\alpha_{\varepsilon 0}.a$ = *his*

$\alpha_{\varepsilon 1}$ = *injured*

$\alpha_{\varepsilon 0}$ = *leg*

V_0 = *hurts*

[**S_1 = *m*A + 2*p* + V + *n*©** ($m, n \geq 0$); $S_{1(36)} = 2p + V$]

(2) Equation of 'computational thought':

- **K = 2*p* + V + *n*γ** ($n \geq 0$)
- $K_{(36)} = 2p + V$ → **2 elements**

p_1 = "[3rd person sing.] injured leg"

p_2 = "[3rd person sing.] injured leg"

'matrix subaxeme' = "[3rd person sing.] leg"

'non-matrix subaxeme' = "injured"

$p_1 = p_2$

V = "to hurt"

Therefore, we can say that the 'coneme' (36) (2), with notions p_1 and p_2: "wounded lower limb of [3rd person sing.]" and V: "to hurt", is able to be expressed in English but not in Spanish, because in the latter there is a different computational structure to convey this thought: (35) (2). Thus, every 'computational thought' is defined as the sequence of notions modelled according to equation (29.4), which can be represented by means of a natural or artificial language. In this way, we could say that there are two ways of obtaining a 'coneme': (a) from a practical point of view, by extracting it from a sequence of a natural or artificial language; (b) from a theoretical viewpoint -less usually-, by creating a 'coneme' in order to check whether it can be projected onto a sequence of a natural or artificial language.

5. Conclusion

The different analysis offered above have been mapped out according to a multilevel 'top-down' process, which definitely determines the multiple structuring of *SS* as opposed to the so-called 'merge' of N. Chomsky's *Minimalist Program*, characterised by following an exclusively binary 'bottom-up' trajectory (Chomsky, 2007: 4).

Actually, the *SS* follows the Onomasiological perspective (Pottier, 1992) of the production of sentence sequence (Garrett, 1975 and 1989) showing a 'top-down' orientation, which fits better the process of cognitive elaboration of a thought than the other way round. And it is exactly this scenario which has allowed us to formulate: (a) the **equation** in its **morpho-functional dimension** –or **universal equation**– with its four prototypes of linguistic syncretism; (b) its derived unfolding, i.e. the **equation** in its **configurational dimension**, where the complex nature of a sentence is shown insofar as it involves the articulation of different structures of ternary, singular, and binary nature; and, finally (c), the

'computational thought' equation as a way of enabling us to better understand the functioning of human mind and, especially, to also improve its manifestation in an artificial way.

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