

## The Representation of the Temporal Properties of Linguistic Utterances through a Mathematical Model

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In this article we use a mathematical model to encode the temporal properties of linguistic utterances across languages by means of mathematical objects—points, lines, segments, vectors and versors—and the relations established among them in a four-dimensional space. Such temporal properties are encoded through three different systems: *tense*—past, present and future—which locates the utterance on a temporal line, *aspect*—perfectivity and progressivity—which sets the viewpoint of the speaker, and *Aktionsart*, which refers to the structural temporal properties of the utterance such as telicity—whether the event has an endpoint or not—dynamicity—whether a change is conveyed or not—and duration. This model aims to be language independent in order to allow for the codification of the temporal properties of utterances in any language, thus rendering it appropriate to be used as an interlingua in Natural Language Processing (NLP) applications. This would significantly improve the comprehension of natural language in search engines and automatic translation systems, to name two examples. Hence, our ultimate goal is for this model to achieve computational adequacy.

Keywords: tense; aspect; *Aktionsart*; interlingua; Natural Language Processing (NLP); computational adequacy

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## La representación de las propiedades temporales de los enunciados lingüísticos a través de un modelo matemático

En este artículo usamos un modelo matemático para codificar las propiedades temporales de los enunciados lingüísticos en cualquier lengua por medio de objetos matemáticos—puntos, líneas, segmentos, vectores y versores—y las relaciones que se establecen entre ellos en un espacio cuatridimensional. Estas propiedades temporales son codificadas a través de tres sistemas diferentes: *tiempo*—pasado, presente y futuro—que ubica el enunciado en una línea temporal, *aspecto*—perfectividad y progresividad—que configura el punto de vista del hablante, y *Aktionsart*, que hace referencia a propiedades temporales estructurales de los enunciados, como la telicidad—si el evento tiene un punto final o no—la dinamicidad—si hay cambio o no—y la duración. Este modelo aspira a ser independiente de lenguas particulares de tal forma que permita la codificación de las propiedades temporales de los enunciados en cualquier lengua, lo que lo hace idóneo como interlengua en aplicaciones de Procesamiento del Lenguaje Natural (PLN), mejorando significativamente la capacidad de estas aplicaciones de comprender el lenguaje natural en motores de búsqueda, así como en sistemas de traducción automática. Por lo tanto, nuestro objetivo es que este modelo alcance adecuación computacional.

Palabras clave: tiempo; aspecto; *Aktionsart*; interlengua; Procesamiento del Lenguaje Natural (PLN); adecuación computacional

## I. INTRODUCTION

The temporal properties of a linguistic utterance—i.e., whether the event is past, present or future; whether the aspect is perfective, aorist or progressive; whether the event is telic or atelic; whether punctual or durative, among others—are essential for its accurate characterization and correct interpretation. The predicates in (1) and (2) have the same propositional meaning— $\exists e (\text{rain}(e)) \wedge \exists e \forall x (\text{wet}(x,e))$ —but a different temporal reference and aspectual perspective: (1) is in the present tense and progressive aspect while (2) is in the past tense, and therefore each entails radically different logical implications. Consequently, in Spanish, a concessive clause like (3) can be true with (2) but not with (1):

(1) Está lloviendo mucho y se está mojando todo.  
 be.3p.sg.pres raining a lot and se.cl. be.3p.sg.pres. getting wet all  
 “It is raining a lot and everything is getting wet.”

(2) Llovió mucho y se mojó todo.  
 rain.3p.sg.past a lot and se.cl. get.3p.sg.past wet all  
 “It rained a lot and everything got wet.”

(3) ...pero ahora el suelo está seco.  
 ...but now the floor be.3p.sg.pres. dry  
 “...but now the floor is dry.”

Languages grammaticalize different temporal properties in different ways. Starting with Proto-Indo-European (PIE), it has been argued that aspectual distinctions such as aorist versus imperfect constitute the primary semantic categories lexicalized in its verbal system, while the proper temporal distinctions such as past versus nonpast appeared later on in the history of PIE through the grammaticalization of lexical elements that expressed temporal relations such as the temporal maker \*-i, which was added to the roots of verbs (Giannakis 1993).

As such, the materialization of temporal properties can vary significantly across different languages, as we can see in the codification of tense in Romance and Germanic languages. In the former, three tenses—present, past and future—can be codified directly by verbal morphology, as in (4) below, while in the latter only the distinction between past and nonpast can be codified in this way, and the future has to be expressed through lexical elements such as adverbs of time like *morgen* in (5) and *tomorrow* in (7), or through modals derived from the grammaticalization of verbs whose meanings are related to desire or willingness—*zullen* in Dutch (6) or *will* in English (8).

(4) a. J'arrive.  
 arrive.1p.sg.pres.  
 “I arrive.”

b. Arrivai.  
arrive.1p.sg.past  
“I arrived.”

c. Llegaré.  
arrive.1p.sg.fut.  
“I will arrive.”

(5) *Morgen* kom ik terug.  
tomorrow come I back  
“I’ll come back tomorrow.”

(6) Ik zal terug komen.  
I shall back back come  
“I’ll come back.”

(7) The train arrives *tomorrow*.

(8) I *will* arrive.

Even if we compare temporal morphology that seems similar in two or more languages, semantic differences may arise. This is the case of the so-called *Present Perfect Puzzle* that consists in the impossibility, in certain languages like English, for a present perfect to co-occur with certain temporal adverbials, as in (9) below. On the contrary, Spanish (10), as well as some Germanic languages such as Dutch (11), do allow such temporal adverbials with the present perfect (Giorgi and Pianesi 1997):

(9) Peter has left (\**at ten*).

(10) Pedro se ha ido (*a las diez*).  
Pedro se.cl have.3p.sg.pres left at the ten  
“Pedro left at ten.”

(11) Piet is weggegaan (om tien).  
Piet is left (at ten)  
“Piet left at ten.”

What is more, even in languages that allow temporal adverbials with the present perfect, further differences can arise, such as the so-called *24-hour rule* in Spanish, a constraint on the temporal distance between the event and the time when the speaker produces the utterance. This distance cannot exceed twenty-four hours as can be seen in (12); in other words, the event time and the time the speaker makes the utterance

must take place within the same day (Comrie 1985; Giorgi and Pianesi 1997).<sup>1</sup> This constraint does not hold in other languages that allow temporal adverbials with the present perfect such as Dutch, as can be seen in (13).

- (12) a. Ana se ha ido a las cinco.  
 Ana se.cl. have.3p.sg.pres. left at the five  
 “Ana left at five.”  
 b. \*Ana se ha ido ayer.  
 Ana se.cl. have.3p.sg.pres. left yesterday  
 “Ana left yesterday.”

- (13) a. Marie is weggegaan om vijf.  
 Marie is left at five  
 “Marie left at five.”  
 b. Marie is laatste week weggegaan.  
 Marie is last week left  
 “Marie left last week.”

Another example can be found in the codification of temporal properties across languages through different lexical elements. In Dutch the adverb *net*, together with the present perfect, codifies that the event finished at nearly the same time as the moment the speaker makes the statement (14). If we were to translate that statement into Spanish, we would have to use the verbal periphrasis *acabar de* + infinitive instead of an adverb, as can be seen in (15). In Italian the adverb *appena* is used to express the same meaning, also with the present perfect (16), while in French this is done through the periphrastic *passé récent* (*venir de* + infinitive) as shown in (17). The same temporal relation is thus expressed by means of different parts of speech in different languages.

- (14) Ik heb net gearriveerd.  
 I have just arrived  
 “I’ve just arrived.”

- (15) Acabo de llegar.  
 finish.1p.sg.pres. of arrive  
 “I’ve just arrived.”

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<sup>1</sup> A reviewer noted that despite the 24-hour rule exemplified in (12), sentences such as *Este mes he abierto una cuenta nueva en el banco* (“This month I have opened a new account in the bank”) are perfectly possible because the time frame of the event and the speech are still connected, so Spanish would seem to be in an intermediate position between Dutch, on the one hand, and English, on the other hand, which is more restrictive in this sense: *I have studied this morning* would be acceptable for most speakers only if the utterance itself happens during the morning.

(16) Sono                    appena    arrivato.  
       be.1p.sg.pres    just        arrived  
       "I've just arrived."

(17) Je    viens                    d'arriver.  
       I    come.1p.sg.pres    of+arrive  
       "I've just arrived."

We can see that there are great differences in the grammaticalization of temporal properties between languages and there are even languages, such as Pirahã, that do not seem to codify any temporal property (Everett 2005). To date, that is a major problem not only for translation between different languages but also for Natural Language Processing (NLP) system applications, such as semantic search engines or deep semantics automatic translators, which are based on the comprehension of linguistic utterances expressed in natural language (Periñán Pascual and Mairal Usón 2010).

In this study, we use a mathematical model that allows us to represent the temporal properties of linguistic statements across languages. Our intention is to describe how these properties can be encoded in a language-independent mathematical model rather than to fully explain their grammaticalization and interpretation, which falls beyond the scope of this article. The model we put forward is meant to identify the primitives of an interlingua for NLP systems, which means that we seek computational adequacy rather than descriptive, explanatory or cognitive adequacy. The model aims to be as theory neutral as possible despite the fact that its theoretical underpinnings, which we have developed elsewhere (2015) and are reviewed in section 2, are based on Hans Reichenbach's (1947) and Zeno Vendler's (1967) systems as well as on image schemata (Johnson 1987) and conceptual metaphors (Lakoff and Johnson 1980a, 1980b) from the framework of cognitive linguistics. In sections 3, 4, 5 and 6 we go into detail about the model, which is machine tractable and should potentially be applicable to any language. This would mean that the model could be adopted by any NLP application as an interlingua, as is briefly illustrated in section 7. Finally, in section 8 the conclusions are presented.

## 2. THEORETICAL BACKGROUND

Reichenbach developed one of the most illuminating and simple theories of time in language ever, which provides a system to understand how tense and aspect are encoded in English. This system consists of three temporal points that, once aligned along a line that represents time, accounts for all tenses attested in English:

- *Speech time* (S): it corresponds with the time point of the act of speech that reports on a certain state of affairs.
- *Event time* (E): it corresponds with the time when the state of affairs takes place.

- *Reference time* (R): Reichenbach did not provide a definition for this temporal point but introduced it in order to account for the differences between sentences like *Peter had gone*” and *Peter went* (1947, 288), both which convey an event that occurred in the past, i.e., the point of event E precedes the point of speech S. The difference between the two sentences lies in the reference time R: “From a sentence like ‘Peter had gone’ we see that the time order expressed in the tense does not concern one event, but two events, whose positions are determined with respect to the point of speech. [...] the point of the event is the time when Peter went; the point of reference is a time between this point and the point of speech” (Reichenbach 1947, 288).

Wolfgang Klein argued that R in fact behaves as a topic time (1992). In other words, R is the time about which a particular claim is made. Similarly, Alessandra Giorgi and Fabio Pianesi argued that “the claim made about R is that the relevant theta-relation holds—or is said to hold—of the subject at R” (1997, 94). Thus, we will be assuming throughout this article that R is both the time when the speaker evaluates the event, and the time when the thematic relations between the event and the topic—usually the subject—as well as the consequences of the event hold.

Very roughly speaking, English simple deictic tenses—past, present and future—are derived from the different ordering relations between R and S (R-S; S-R; S,R) and assume the coincidence of R and E (R,E). Thus, the simple past tense means that the event E occurs and is evaluated before the point when the speech is uttered (18); the present tense means that the event E occurs and is evaluated at the same time as the speech act (19); and the future tense means that the event E occurs and is evaluated after the speech act time point (180):

(18) I saw a nice thing. (E,R-S)

(19) I see a nice thing. (E,R,S)

(20) I will see a nice thing. (S-R,E)

Reichenbach noted that the English tense system is in fact considerably more complex than this, since the reference temporal point R may occur before or after the other two points (E and S). For example, in the past perfect tense (21), there are two temporal points: the point of event E and the point R when the speaker evaluates the truth conditions of the event. Both of them come before the speech point S, so the past perfect is represented as E-R-S. This contrasts with the present perfect (22), where the speaker utters (S) and evaluates (R) the truth conditions of the event that has occurred before both points, at the same time—hence E-S,R.

(21) I had never seen such a nice thing before.

(22) I have never seen such a nice thing before

Reichenbach's system is not the only one that has tried to account for English tenses (see, among others, Ward 1963; Prior 1967; Bennett and Partee 1972, Smith 1978; Dowty 1979; Comrie 1985; Declerck 1986). It has been adopted in generative linguistics by scholars like Norbert Hornstein (1990), Giorgi and Pianesi (1997), Hamida Demirdache and Myriam Uribe-Etxebarria (2000), who provide a structural syntactic representation that accounts for both tense and aspect.

Other temporal properties that are not part of tense and aspect, though they may interact with them, were first noted by Aristotle, who defined the concept of *telos*. These properties were brought to modern linguistics by Vendler (1967), who studied states of affairs and identified three basic features of their temporal structure, traditionally called *Aktionsart*:

- *Telicity* is the property of a state of affairs that has an end point, while *atelicity* is the property of a state of affairs that has no end point.
- *Duration* is the extension of time over which the state of affairs takes place, compared to *punctuality*, which is the property of a state of affairs that has no duration but is instantaneous.
- *Dynamicity* is the property of a state of affairs that changes over time, and contrasts with *stativity*, the property of a state of affairs that does not change over time.

On the basis of these features, Vendler defined four basic types of states of affairs, namely, *states*, *activities*, *accomplishments* and *achievements*. States are static, durative and atelic (23); activities are dynamic, durative and atelic (24); accomplishments are dynamic, durative and telic (25); achievements are dynamic, punctual and telic (26):

(23) a. I love cats.  
 b. I know what you did last summer.  
 c. I don't feel very well right now.

(24) a. John built houses.  
 b. I run in the mornings.  
 c. I ate loads of donuts when I was younger.

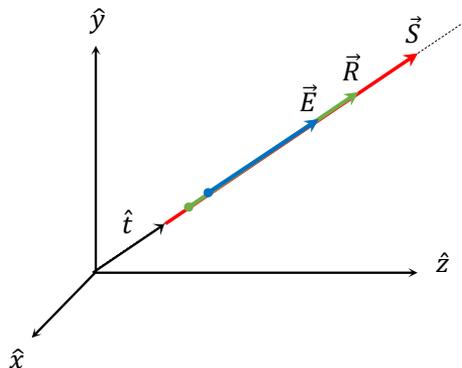
(25) a. John built the house.  
 b. I read the book in two hours.  
 c. I ate three donuts this morning.

- (26) a. I noticed that there was something wrong.  
 b. I finally found the keys.  
 c. After a long time, I finally figured it out.

In the wake of Vendler's seminal paper, many other scholars have provided a deeper understanding of *Aktionsart* and its interaction with tense and aspect, as well as a refinement of the taxonomy of states of affairs (see, among many others, Verkuyl 1972, 1993; Krifka 1998; Levin 2000; Borik 2004; Borik and Reinhart 2004; Borer 2005; Mani et al. 2005).

Building on Reichenbach's and Vendler's contributions, in "Tense in a Vectorial Model for the Conceptualization of Time" (2015) we proposed a four-like dimensional mathematical model to represent how time is conceptualized in natural languages based on Mark Johnson's image schemas (1987). We followed Olga Borik (2002) and Borik and Tania Reinhart (2004) and assumed that tense—past, present, future—aspect—perfectivity, imperfectivity and progressivity—and *Aktionsart*—states, activities, accomplishments, achievements and semelfactives—are three different and independent systems that can be codified by certain mathematical objects—points, lines, segments, vectors and versors—that correspond to the Reichenbachian temporal points in a three-dimensional space):

FIGURE 1. The temporal vectors corresponding to the Reichenbachian S, E and R times



Speech time is a point S and thus has a corresponding position vector  $\vec{S}$ .<sup>2</sup> The use of this vector, which is not the speech time itself but the position vector that locates it,

<sup>2</sup> Any point A in a three-dimensional space has a corresponding position vector whose initial point is (0,0,0) and whose terminal point is A. So, the speech time point S has a corresponding position vector whose initial point is (0,0,0) and whose terminal point is S.

allows operations to be conducted with other mathematical objects representing various other temporal properties. Reference time is a vector  $\vec{R}$ . Event time is a mathematical object whose nature, as we will see in section 6, depends on the temporal structure of the event, i.e., its *Aktionsart*: it can be a line—states—a segment  $\vec{E}$  (bound states)—a vector  $\vec{E}$ —activities and accomplishments—or a versor —  $\hat{E}$  achievements and semelfactives.

We outlined this space by means of three-path image schemas that delineate the x, y and z axes. These path image schemas can be expressed by means of their corresponding  $\hat{x}$ ,  $\hat{y}$  and  $\hat{z}$  versors, which are segments with directionality whose magnitude equals 1. These versors trace the lines that, in their turn, define the axes. Time is another dimension, established by a different path image schema, mathematically represented by the versor  $\hat{t}$ , which traces a temporal t axis that is inserted in the three-dimensional space in order to locate the proposition conveyed by the linguistic utterance in space and time. Like many other scholars, we argued that time cannot be directly perceived as a fourth dimension by the human conceptual system, so we have to draw on the conceptual metaphor TIME IS SPACE (Gentner et al. 2002; Casasanto and Boroditsky 2008; Brala Vukanović and Gruić Grmuša 2009; Choi 2009; Merrit et al. 2010; Sinha and Bernárdez 2015), which makes it possible to conceptualize time by means of a path image schema. Thus, we suggested that the temporal-spatial space where the propositions conveyed by linguistic utterances are interpreted is not a real four-dimensional space  $R^4$ , but a four-like dimensional space outlined by a three-dimensional space plus an auxiliary temporal axis  $R^3+t$ . While in our 2015 article we only provided the codification of the three simple tenses—past, present and future—to demonstrate the potential of our model, here we build a mathematical model that modifies and further develops our previous proposal so that tense, aspect and *Aktionsart* can be integrated.

### 3. MATHEMATICAL OBJECTS IN A FOUR-DIMENSIONAL SPACE ( $R^4$ )

In this article, we propose a real four-dimensional space—unlike the four-like dimensional space we introduced in (2015)—composed of the three spatial axes x, y and z defined by three versors  $\hat{x}$ ,  $\hat{y}$  and  $\hat{z}$  and one temporal axis t defined by versor  $\hat{t}$  because, as already mentioned, we want this model to achieve computational adequacy, and a real four-dimensional space can be used in the NLP applications where our model will be integrated (see section 7). We assume that only one axis (t) is sufficient to encode all the temporal properties because it has been proven that time is perceived as a linear function (Wearden and Jones 2007; Weger and Pratt 2008).

Other models, like Hornstein's (1990) and Demirdache and Uribe-Etxebarria's (2000), have argued that the temporal Reichenbachian variables R, E and S are better represented as segments or intervals rather than points, which sufficed because these models focused mostly on tense and aspect and left *Aktionsart* aside. While we agree with these scholars that these temporal variables are not best captured as points, we need to take a step further by introducing vectors in the analysis of time in order to

integrate *Aktionsart*, for which the notion of dynamicity—whether the state of affairs entails a change—is crucial. A vector is a segment that has directionality and sense, i.e., it involves movement—a change—from an initial to a final point, as is the case with activities, accomplishments, achievements and semelfactives. On the other hand, segments and lines, which lack directionality and sense, will suffice to encode states of affairs that do not entail any change, such as states (see section 6).

A vector is generically denoted as  $\overrightarrow{AB}$  and is characterized by the following elements:

- An initial point A, represented as  $[A, (\overrightarrow{AB})]$
- A terminal point B, represented as  $[B, (\overrightarrow{AB})]$
- A magnitude M, represented as  $[M, (\overrightarrow{AB})]$ , which is a number multiplied by an abstract unit
- A direction, defined by the segment formed between the initial point and the terminal point
- A sense, represented as  $[S, (\overrightarrow{AB})]$ , which is positive if the initial point is  $[A, (\overrightarrow{AB})]$  and the terminal point is  $[B, (\overrightarrow{AB})]$ , and negative if the initial point is  $[B, (\overrightarrow{AB})]$  and the terminal point is  $[A, (\overrightarrow{AB})]$
- A versor, represented as  $\overrightarrow{AB}$ , is a vector whose magnitude is one:  $[M, (\overrightarrow{AB})]=1]$

The temporal properties of the propositions conveyed by linguistic utterances are exhaustively codified by the relations among three mathematical objects that correspond to the three Reichenbachian temporal points S, E and R:

- We assume speech time is a point S in a four-dimensional space.<sup>3</sup> As such, it has a corresponding position vector  $\vec{S}$  whose initial point is (0,0,0,0) and whose terminal point is S. The position vector  $\vec{S}$ , rather than the speech time point S, is the element that will establish the relations that exist with the other temporal objects in the system.
- We assume reference time is a vector because it is a period of time that goes from past through present to future, and hence directionality and sense are required to encode it.
- The time of event E is represented by different objects depending on whether the state of affairs involves a change or not. If it does not, as in states, an object without directionality or sense, such as a line or a segment can encode the state of affairs. If the state of affairs does, however, entail a change, as activities, accomplishments, achievements and semelfactives do, then it will be codified by an object with directionality and sense such as a vector or a versor .

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<sup>3</sup> We are aware that we depart from Michael Bennett and Barbara Partee (1972), as well as from much of the literature on tense, in assuming that speech time is a point. We do this for the sake of simplicity and because we assume that the period of time in which the speaker makes the utterance cannot be broken by any other event, and so it is, in a sense, quasi-punctual. In the future, we plan to reconceptualize speech time and define it either as a segment  $\vec{S}$  or as a vector  $\vec{S}$  in order to better account for the temporal structure of narrative.

It is important to note that this model relies on relations established between the previously defined temporal vectors and/or the points that define them, rather than on absolute temporal values. We would argue that this is all that is needed to codify any temporal property that is conveyed in any human language. In fact, the same holds for space too, though we will not elaborate on this here. If we look closely at the semantics of temporal morphemes, prepositions and adverbials, it is apparent that they convey a relational meaning between two elements. For example, and as argued in section 2, the simple past tense denotes a precedence relation between the time of the event and the speech act time. The Dutch adverb *net* in (14) expresses a coincidence between two elements: the final point of the event  $E$  ( $\vec{E}/\vec{E}/\hat{E}$ ) and the point of speech  $S$  (i.e., the terminal point of  $\vec{S}$ ). We will see in the remainder of this article that all the temporal properties to be conveyed in human languages can potentially be encoded in this system, although we will not implement all of them for reasons of space.

#### 4. TENSE AND THE CODIFICATION OF PAST, PRESENT AND FUTURE

Tense is a property that locates the state of affairs conveyed by a proposition along a temporal line and in relation to the time the utterance is produced; in other words, it comes from the relations established between the Reichenbachian event and speech times. In our model, we follow Michael Bennett and Barbara Partee (1972) in assuming that simple deictic tenses come from the relations established between the  $\vec{R}$  and  $\vec{S}$  vectors in an  $R^4$  space, and further assume that  $\vec{R}$  and  $E$  ( $\vec{E}/\vec{E}/\hat{E}$ ) coincide.<sup>4</sup> In order to explain which relations, and how many, are needed to encode Reichenbach's three tenses—past, present and future (1947)—we will make use of two operations from Set Theory on our  $\vec{R}$  and  $\vec{S}$  vectors: intersection ( $\cap$ ) and inclusion ( $\subseteq$ ).

As we have already said, the present tense implies that a state of affairs, encoded by  $E$  ( $\vec{E}/\vec{E}/\hat{E}$ ), takes place and is evaluated at the same time as the speaker utters the speech act, encoded by  $S$ .<sup>5</sup> This is what defines the present tense, regardless of whether  $E$  ( $\vec{E}/\vec{E}/\hat{E}$ ) began before or at the same time as  $S$ , which is encoded by aspect (see section 5), lexical elements like *net* in (14) or world knowledge. For instance, all the examples in (27) are in the present tense despite the fact that the state of affairs is understood to have begun a bit earlier than  $S$  in (27a), a lot earlier than  $S$  in (27b) and at roughly the same time as  $S$  in (27c).

- (27) a. I'm reading the book you lent me.  
 b. The earth moves around the sun.  
 c. I'm just starting to read the book you lent me.

<sup>4</sup> We leave out the analysis of anaphoric tenses due to space restrictions.

<sup>5</sup> It should be remembered that although we assume the speech time is a point in the four-dimensional space, it has a corresponding position vector  $\vec{S}$ , that is, the object that will establish a relation with  $\vec{R}$  and  $E$  ( $\vec{E}/\vec{E}/\hat{E}$ ).

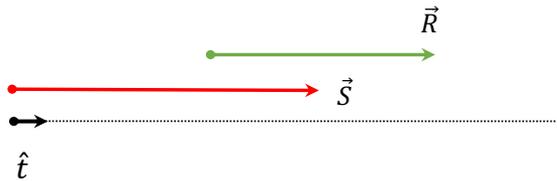
Further, for a state of affairs that is in the present tense nothing is implied about its ending point, only that it cannot finish before the point of speech. This can be formulated as (28) by making use of inclusion and intersection relations between the vectors and in a  $\mathbb{R}^4$ , assuming that  $\vec{E}$  and  $\vec{E}$  coincide:

(28) Present tense

- a.  $\vec{R} = E(\vec{E}/\vec{E}/\hat{E})$
- b. The intersection between vectors  $\vec{R}$  and  $\vec{S}$  is different from zero:  $\vec{R} \cap \vec{S} \neq \emptyset$
- c. As for inclusion, vector  $\vec{S}$  does not contain vector  $\vec{R}$ :  $\vec{R} \notin \vec{S}$

This can be represented as in figure 2, where only the temporal dimension of the  $\mathbb{R}^4$  is represented for the sake of simplicity.

FIGURE 2. Present tense



A state of affairs that is in the past tense takes place and is fully interpreted before the speech point, that is to say,  $E(\vec{E}/\vec{E}/\hat{E})$  both starts and finishes before  $S$ . This is formalized in (29) by using inclusion and intersection relations between the vectors  $\vec{R}$  and  $\vec{S}$  in an  $\mathbb{R}^4$  as follows, assuming that  $\vec{R}$  and  $E(\vec{E}/\vec{E}/\hat{E})$  coincide, and represented in figure 3.

(29) Past tense

- a.  $\vec{R} = E(\vec{E}/\vec{E}/\hat{E})$
- b. The intersection between the vectors  $\vec{R}$  and  $\vec{S}$  is different from zero  $\vec{R} \cap \vec{S} \neq \emptyset$
- c. As for *inclusion*, the vector  $\vec{S}$  contains the vector  $\vec{R}$  but the vector  $\vec{R}$  does not contain the vector  $\vec{S}$ :  $\vec{R} \in \vec{S} \wedge \vec{S} \notin \vec{R}$

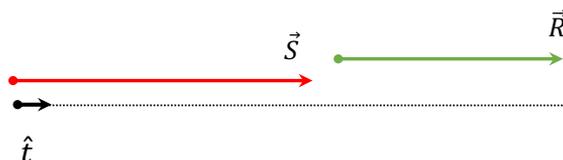
FIGURE 3. Past tense



Finally, a state of affairs is in the future tense if it has not begun or been evaluated by the time of speech, and thus has not finished by the time of speech. So  $E(\bar{E}/\vec{E}/\hat{E})$  takes place after  $S$  and they do not coincide whatsoever. In order to codify this, we have used only the intersection between vectors  $\vec{R}$  and  $\vec{S}$ , assuming that  $\vec{R}$  and  $E(\bar{E}/\vec{E}/\hat{E})$  coincide:

- (30) Future tense  
 a.  $\vec{R} = E(\bar{E}/\vec{E}/\hat{E})$   
 b. The intersection between the vectors  $\vec{R}$  and  $\vec{S}$  is zero:  $\vec{R} \cap \vec{S} = \emptyset$

FIGURE 4. Future tense



## 5. ASPECT AND THE CODIFICATION OF PERFECTIVITY, IMPERFECTIVITY AND PROGRESSIVITY

We propose that the outer aspect system, which codifies perfectivity, imperfectivity and progressivity, is independent of the systems that codify tense (see section 4) and inner aspect or *Aktionsart* (see section 6), as Borik (2002) and Borik and Reinhart (2004) have argued. This system is derived from the relations established between  $E(\bar{E}/\vec{E}/\hat{E})$  and the  $\vec{S}$  and  $\vec{R}$  vectors.

Valentina Bianchi et al. argued that  $R$  is a perspective time and acts as a time from which the event is considered (1995, 314). If the event is progressive, it is seen as going on at the perspective time  $R$ . If the event is perfective, it is perceived as completed. In section 2, we explained our assumption that  $R$  is both the time when the speaker evaluates the event, and the time when the thematic relations between the event and the topic as well as the consequences of the event hold. Consequently, in our system the  $\vec{R}$  vector encodes this time period. Taking the sentences in (31) by way of example,

all three share the same basic propositional content, i.e., an event—a concert—and the time at which it holds true—October 22—which is the reference time—the date when the concert takes place. In all three sentences, R and E coincide. The only difference between the sentences in (31) is the position of S with respect to E and R: after, as in (31a), which yields a past tense; simultaneous, as in (31b), yielding a present tense; and before, as in (31c), yielding a future tense:

- (31) a. The concert was on October 22.  
 b. The concert is taking place today, which is October 22.  
 c. The concert will be on October 22.

If we look at British English present perfect tense, we see that perfective aspect implies that an event in the past has ended long or just before S its consequences are somehow still active.<sup>6</sup> The difference between the sentences in (32), which share the same propositional content— $\exists e (\text{eat}(e)) \wedge (\text{agent}(\text{John}, e)) \wedge (\text{theme}(\text{cake}, e))$ —is that in (32a) the consequences of John's eating the cake are still active, such that he has a stomach ache, while (32b) does not entail any consequence that is active in the present:

- (32) a. John has eaten the cake.  
 b. John ate the cake.

In our system, this implies that vector  $\vec{R}$  has to be contained within position vector  $\vec{S}$  and, thus, there is a terminal coincidence of both to the extent that the consequences of the event are active in the present but not in the future. A terminal coincidence between these vectors means that  $\vec{R}$  and  $\vec{S}$  coincide in their final points, which triggers present tense verbal morphology in English. The event is interpreted in the past because  $E (\vec{E}/\vec{E}/\hat{E})$  is contained in and they do not coincide. This can be codified and represented as follows:

- (33) Perfective aspect  
 a. Terminal coincidence  $\vec{R}$  and  $\vec{S}$  :  $[B, (\vec{R})] = [B, (\vec{S})]$   
 b.  $E (\vec{E}/\vec{E}/\hat{E}) \in \vec{R} \wedge \vec{R} \notin E (\vec{E}/\vec{E}/\hat{E})$   
 c.  $E (\vec{E}/\vec{E}/\hat{E}) \neq \vec{R}$

FIGURE 5. Perfective aspect



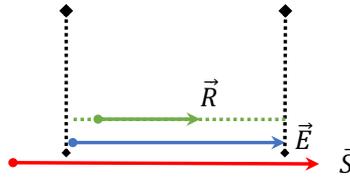
<sup>6</sup> Please see footnote 5.



codify as  $\vec{R}$  moving along  $E(\vec{E}/\vec{E}/\hat{E})$  while  $E(\vec{E}/\vec{E}/\hat{E})$  remains fixed. In other words,  $\vec{R}$  is a free sliding vector and, as such, it has no application point, that is, its initial and terminal points have no fixed values. Since we do not wish  $\vec{R}$  to slide further than the terminal point of  $E(\vec{E}/\vec{E}/\hat{E})$  because that would entail an interpretation different from the progressive aspect, we must state that  $\vec{R}$  is included in  $E(\vec{E}/\vec{E}/\hat{E})$ , and thus that the event began before  $\vec{R}$  and ended, or will end, after  $\vec{R}$ . Its evaluation, therefore, will not extend beyond the time over which the event takes place. This can be codified as in (37) and graphically represented as in figure 7:

- (37) Progressive aspect  
 a.  $\vec{R} \in \vec{E} \wedge \vec{E} \notin \vec{R}$   
 b.  $\vec{R} = \text{sliding vector} \rightarrow [A,(\vec{R})] = \emptyset \wedge [B,(\vec{R})] = \emptyset$

FIGURE 7. Progressive aspect



In a sense, progressivity and imperfectivity are quite similar. In both, the reference time is contained within the event time so it is perceived that the event began before it started to be evaluated and ended, or will end, after its evaluation. The difference between the two is that the imperfective aspect does not entail movement of either  $E(\vec{E}/\vec{E}/\hat{E})$  or  $\vec{R}$ , while the progressive aspect does entail movement of  $\vec{R}$  along  $E(\vec{E}/\vec{E}/\hat{E})$ . As a result, in the former the focus is on the event progression while in the latter it is on the evaluation itself, that is to say, on the movement of  $\vec{R}$ . Hence, in the former both  $\vec{R}$  and  $E$  (are objects with application points, which ensures both vectors are fixed and do not move, while in the latter  $E$  () is still an object with an application point and thus fixed, but  $\vec{R}$  has no application point, which renders it a free sliding vector that can move along  $E(\vec{E}/\vec{E}/\hat{E})$ . This solution is proposed in order for our model to be able to successfully encode the differences between progressivity and imperfectivity and, thus, for it to achieve computational adequacy.

## 6. AKTIONSPORT AND THE CODIFICATION OF DYNAMICITY, TELICITY AND DURATION

In section 2, we defined the types of states of affairs—states, activities, accomplishments and achievements—and mentioned some of the properties—telicity, duration and dynamicity—that make up their internal temporal structure or *Aktionsart*,

as initially identified by Vendler (1967). We propose to encode the *Aktionsart* of the state of affairs through certain properties of the geometrical E object: its nature—whether it is a line, a segment or a vector—its magnitude and its initial, terminal and application points, and accordingly represent it as a line (E), a segment ( $\bar{E}$ ), a vector ( $\vec{E}$ ) or a versor ( $\hat{E}$ ).<sup>7</sup>

Stativity, or lack of dynamicity, will be encoded in our system by defining the E object, i.e., the time during which the event takes place, as a line. States like (38) do not involve any change and thus, no dynamicity, meaning that a line is sufficient to represent their temporal structure. This line can be defined by only one point, represented by a Latin letter—for example, C in figures 8 and 9—and therefore no initial or final points are needed to further define it. Actually, such points are rather limits to infinite ( $\lim \infty$ ), as represented in figure 8. This reflects the fact that states do not have any temporal boundary, unless a duration adverbial like a *for*-clause in (38b) is added, which compositionally defines an initial and/or final point and renders E a linear segment  $\bar{E}$ , as represented in figure 9:

- (38) a. I love my mother.  
b. I loved that dog for the eighteen years it lived.

FIGURE 8. Unbound state

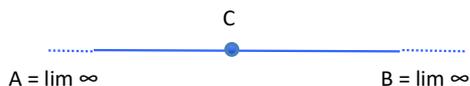
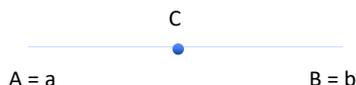


FIGURE 9. Bound state



Duration is important for states of affairs that imply dynamicity such as accomplishments, as in (39). We will encode duration by means of a segment defined by an initial A and a terminal B point, which define the boundaries of the accomplishment, expressed by different constituents like the prepositional phrase *in two and a half hours* in (39a) and the prepositional phrase *in five minutes* in (39b). Accomplishments are always bound, even if there is no constituent that overtly expresses such boundaries, as

<sup>7</sup> See Aparicio et al. (2013) for an alternative proposal to codify *Aktionsart* and the inner structure of the events in a way that is applicable to NLP.

in (39c). Together with duration, dynamicity has to be encoded since accomplishments imply a change. For example, in (39b) the state of the pizza at moment 0, in which the pizza is still whole (uneaten), is different from its state at the final moment of the accomplishment, when it is finished (eaten), thus it does not exist anymore. This is done by defining  $E$  as vector  $\vec{E}$  from  $A$  to  $B$ , as shown in figure 10, rather than a line or a bound segment. This implies that it has initial and terminal points, direction, sense and magnitude, as was argued in section 3.

- (39) a. John read that book in two and a half hours.  
 b. Peter ate the whole pizza in five minutes.  
 c. Mary built the house.

FIGURE 10. Accomplishment



*In*-adverbials, as in (39a) and (39b), provide the magnitude of the vector  $M(\vec{E})$ . Finally, the terminal point  $B$  is sufficient to define a line that encodes a state that is the result of the accomplishment, as represented in figure 11. For example, the accomplishment of Peter's eating the pizza in (39.b) brings about a change in the pizza, namely that it does not exist anymore. The accomplishment of Mary's building the house in (39c) brings about a change in terms of the house that comes into existence as a result of the accomplishment.

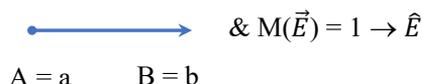
FIGURE 11. Accomplishment with a result state



Achievements such as those in (40), like accomplishments, are dynamic events but have no duration, that is to say, they are instantaneous or punctual. We represent this by stating that their magnitude equals the abstract temporal unit  $M(\vec{E}) = 1$  and that this is codified in the lexicon. As previously said, vectors with a magnitude  $M=1$  are called versors, so achievements are versors and are represented as in figure 12:

- (40) a. Ann realized she was wrong.  
 b. Mary found the keys you lost this morning.  
 c. John caught a cold.

FIGURE 12. Achievement



The magnitude of achievements is fixed and cannot be modified compositionally by means of duration adverbials, unlike accomplishments, which have their magnitude unmarked in their lexical specification so that other elements in the clause can determine its value.

The last temporal property to be encoded in our system is telicity, which indicates that a state of affairs has an end point like the accomplishments in (39)—in (39a) it is implied that John read the whole book and the event of reading was completed; in (39b) it is implied that Peter ate the whole pizza and the event of eating was completed in five minutes, and so is the result state, that is to say, that there is no pizza left; in (39c) it is implied that Mary built the house and that the event is ended, its result state being the existence of the house. Other states of affairs, like the activities in (41), are not telic and, thus, do not entail any end point—(41a) does not imply that John has finished reading any books; (41b) does not entail that Peter ate one, two or any number of whole pizzas; (41c) does not entail that Mary's building of houses has ended; and in (41d) we cannot tell if Eneko finished whatever he was drinking.

- (41) a. John reads books.  
 b. Peter ate pizza at my party.  
 c. Mary builds houses for a living.  
 d. Eneko drank for hours.

Since activities are dynamic, they are represented by bound vectors, like accomplishments and achievements. However, since they are atelic, they cannot have a terminal point that bounds the event. We codify this by defining the value of their terminal point B as a limit ( $\lim \infty$ ) rather than as a natural number represented by the letters a, b, c, etc.:

FIGURE 13. Activities



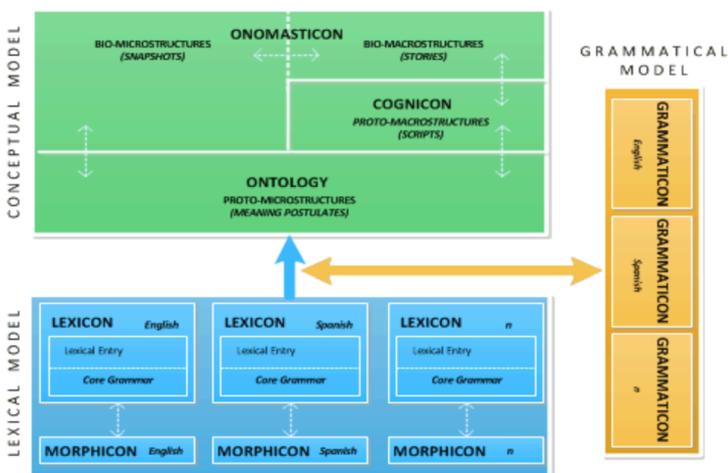
Since limits are not points, they cannot further define a line and, therefore, no result state can be defined. *For*-adverbials like *for hours* in (41d) cannot modify the magnitude of activities since they have no terminal point, but they can define the magnitude of the vector  $\vec{R}$ , which necessarily must include  $\vec{E}$ .

Having codified the three main temporal properties that define the *Aktionsart* of states of affairs—telicity, duration and dynamicity—along with the past, present and future tenses and the perfective, imperfective and progressive aspects, virtually all the temporal properties to be expressed in languages like English and Spanish, among others, can be encoded by means of language-independent elements. In the next section, we briefly discuss how this model can be implemented in an NLP system, FunGramKB, a multilingual and multipurpose lexico-conceptual knowledge base designed to be used for NLP tasks (Periñán Pascual and Arcas Túnez 2010; Periñán Pascual 2013).

## 7. APPLICATIONS IN NLP

FunGramKB has three levels of information: a lexical level that includes a Lexicon and a Morphicon for each of the languages supported; a grammatical level that contains the language-specific Grammaticons; and a conceptual level, shared by all languages (figure 14).

FIGURE 14. The modules of FunGramKB (Periñán Pascual and Arcas Túnez 2011, 3)



The conceptual level contains general knowledge in three subcomponents:

- The Ontology: a hierarchically organized catalogue of concepts that humans have in their mind and that therefore reflects the model of the world shared

by a community (Mairal Usón and Perriñán Pascual 2010). Within it, semantic knowledge is stored in the form of thematic frames and meaning postulates.

- The Cognicon: this is where procedural knowledge is gathered by means of script-like cognitive macrostructures known as schemata.
- The Onomasticon: this is where instances of entities and events are stored through snapshots and stories.

As shown in figure 14, both the Lexicon and the Grammaticon are connected to the conceptual level, from which they retrieve information. Thus, the explanatory scope of lexical entries is increased because encyclopedic knowledge, present in the conceptual level, can be accessed.

FunGramKB uses the logical structures of the Role and Reference Grammar (RRG; Van Valin 2005) to represent the predicates in linguistic utterances, enhanced by the new formalism of Conceptual Logical Structures (CLSs; Perriñán Pascual and Mairal Usón 2010), which integrates concepts from the FunGramKB ontology and operators such as tense and mood. Carlos Perriñán Pascual and Francisco Arcas Túnez argue that CLSs are real language-independent representations since they rely on concepts—from FunGramKB’s ontology—rather than words, and thus they “serve to build a bridge between the conceptual level of FunGramKB and the particular idiosyncrasies coded in a given linguistic expression” (2010, 2671). For example, a sentence like (42) has the CLS in (43) (Perriñán Pascual and Arcas Túnez 2010).

(42) Betty asked Bill for an apple.

(43)  $\langle_{\text{IF}} \text{DECL} \langle_{\text{TNS}} \text{PAST} \langle \{ \text{do}(\% \text{BETTY\_00}_{\text{Theme}}, [+ \text{REQUEST\_01}(\% \text{BETTY\_00}_{\text{Theme}}, \% \text{BILL\_00}_{\text{Goal}})]) \} \text{PURP} \{ \text{do}(\% \text{BILL\_00}_{\text{Goal}}, \text{o}) \} \text{CAUSE} [\text{BECOME} + \text{REQUEST\_01}(\% \text{BETTY\_00}_{\text{Theme}}, + \text{APPLE\_00}_{\text{Referent}})] \rangle \rangle \rangle$

The mathematical objects introduced in the previous sections can replace the CLS temporal operators, such as tense TNS, and expand them to encode temporal information of the utterance with regard to its tense, aspect and *Aktionsart*. The new CLS of (42), an accomplishment in simple past tense, would then be (44):

(44)  $\langle_{\text{IF}} \text{DECL} \langle_{\text{TNS}} \vec{R} = E(\vec{E}/\vec{E}/\vec{E}) \ \& \ \vec{R} \cap \vec{S} \neq \emptyset \ \& \ \vec{R} \cap \vec{S} \wedge \vec{S} \notin \vec{R}_{\text{AKTIONART}} \ E = \vec{E} \ \& \ [A,(\vec{E})] = a \ \& \ [B,(\vec{E})] = b \ \langle \{ \text{do}(\% \text{BETTY\_00}_{\text{Theme}}, [+ \text{REQUEST\_01}(\% \text{BETTY\_00}_{\text{Theme}}, \% \text{BILL\_00}_{\text{Goal}})]) \} \text{PURP} \{ \text{do}(\% \text{BILL\_00}_{\text{Goal}}, \text{o}) \} \text{CAUSE} [\text{BECOME} + \text{REQUEST\_01}(\% \text{BETTY\_00}_{\text{Theme}}, + \text{APPLE\_00}_{\text{Referent}})] \rangle \rangle \rangle$

By integrating our model’s mathematical objects into FunGramKB’s CLSs, they will serve as elements of an interlingua in which the temporal properties of the utterances of any language can be defined. To codify utterances from specific languages into this

interlingua, we need to define linking rules that establish which objects—meaning—are associated to different elements—forms—of that language—verbal morphology, adverbs, etc.—and under which conditions—meaning—these associations are established. For example, the present perfect is quite different in English (45), Dutch (46) and Spanish (47), as discussed in section 1. The common CLS shared by (45), (46) and (47), leaving the temporal adjunct *at ten/a las diez/om tien* aside, is (48):

(45) Peter has left (\**at ten*).

(46) Piet is weggegaan (om tien).

Piet is left (at ten)

“Piet left at ten.”

(47) Pedro se ha ido (a las diez).

Pedro se.cl. have.3p.sg.pres left at the ten

“Pedro left at ten.”

(48) [BECOME +LEAVE\_00 (%PETER\_00/PEDRO\_00/PIET\_00<sub>Theme</sub>)]

We need to define three linking rules to encode the different properties of the present perfect in English, Dutch and Spanish. The English present perfect is not compatible with temporal adverbs because reference time has to be connected to speech time, so we can encode this by saying that the terminal point of  $\vec{R}$  and  $\vec{S}$  must coincide, in addition to the other conditions we defined for the present perfect in section 4. We can thus formulate a linking rule for the English present perfect as in (49). Contrarily, the Dutch present perfect allows temporal adverbs because reference time does not need to be connected to speech time. We can codify this by saying that  $\vec{R}$  has to be included within  $\vec{S}$ , so the Dutch present perfect linking rule would be (50):

(49) English present perfect linking rule

Form: HAVE with present verbal morphology + VERB<sub>-EN</sub>

Meaning: Terminal coincidence  $\vec{R}$  and  $\vec{S}$ :  $[\mathbf{B},(\vec{R})] = [\mathbf{B},(\vec{S})]$

$E(\vec{E}/\vec{E}/\hat{E}) \in \vec{R} \wedge \vec{R} \notin E(\vec{E}/\vec{E}/\hat{E})$

$E(\vec{E}/\vec{E}/\hat{E}) \neq \vec{R}$

(50) Dutch present perfect linking rule

Form: HEBBEN with present verbal morphology + VERB<sub>-EN</sub>

Meaning: Inclusion ( $\vec{R}$  within  $\vec{S}$ ):  $\vec{R} \in \vec{S}$

$E(\vec{E}/\vec{E}/\hat{E}) \in \vec{R} \wedge \vec{R} \notin E(\vec{E}/\vec{E}/\hat{E})$

$E(\vec{E}/\vec{E}/\hat{E}) \neq \vec{R}$

So the full CLS for (45) would be obtained by applying linking rule (49) to (48), which renders (51). And the full CLS for (46) would be obtained by applying linking rule (50) to (48), which renders (52):

$$(51) \text{ } <_{\text{IF}} \text{DECL} <_{\text{TNS}} \vec{R} \cap \vec{S} \neq \emptyset \ \& \ \vec{R} \in \vec{S} \wedge \vec{S} \notin \vec{R} <_{\text{ASPECT}} [\text{B},(\vec{R})] = [\text{B},(\vec{S})] \ \& \ \text{E} (\vec{E}/\vec{E}/\vec{E}) \in \vec{R} \wedge \vec{R} \notin \text{E} (\vec{E}/\vec{E}/\vec{E}) \ \& \ \text{E} (\vec{E}/\vec{E}/\vec{E}) \neq \vec{R} <_{\text{AKTIONSART}} \text{E} = \vec{E} [\text{BECOME} + \text{LEFT\_00} (\% \text{PETER\_00}_{\text{Theme}})] >>>$$

$$(52) \text{ } <_{\text{IF}} \text{DECL} <_{\text{TNS}} \vec{R} \cap \vec{S} \neq \emptyset \ \& \ \vec{R} \in \vec{S} \wedge \vec{S} \notin \vec{R} <_{\text{ASPECT}} \vec{R} \in \vec{S} \ \& \ \text{E} (\ \& \ \text{E} (\vec{E}/\vec{E}/\vec{E}) \in \vec{R} \wedge \vec{R} \notin \text{E} (\vec{E}/\vec{E}/\vec{E}) \ \& \ \text{E} (\vec{E}/\vec{E}/\vec{E}) \neq \vec{R} <_{\text{AKTIONSART}} \text{E} = \vec{E} [\text{BECOME} + \text{LEFT\_00} (\% \text{PIET\_00}_{\text{Theme}})] >>>$$

The 24-hour rule that applies in languages like Spanish (see section 1) can be easily codified by stating the following condition: the magnitude  $M$  of a new temporal vector  $\vec{V}$  formed between the final point of  $\vec{R}$ —which would be its initial point—and the terminal point of the  $\vec{S}$  vector—which would be its final point—cannot be greater than twenty-four hours. So the Spanish present perfect linking rule could be defined as (53) and the CLS of (47) would be (54), which forces the reading that Peter's leaving happened at 10:00 a.m. on the same day as the utterance was made.

(53) Spanish present perfect linking rule<sup>8</sup>

Form: HABER with present verbal morphology + VERB-<sub>EN</sub>

Meaning: Inclusion ( $\vec{R}$  within  $\vec{S}$ ):  $\vec{R} \in \vec{S}$

24-hour rule (I):  $\vec{V} \rightarrow [\text{A},(\vec{V})] = [\text{B},(\vec{R})] \wedge [\text{B},(\vec{V})] = [\text{B},(\vec{S})]$

24-hour rule (II):  $[\text{M},(\vec{V})] \leq 24\text{h}$

$$\text{E} (\vec{E}/\vec{E}/\vec{E}) \in \vec{R} \wedge \vec{R} \notin \text{E} (\vec{E}/\vec{E}/\vec{E}) \\ \text{E} (\vec{E}/\vec{E}/\vec{E}) \neq \vec{R}$$

$$(54) \text{ } <_{\text{IF}} \text{DECL} <_{\text{TNS}} \vec{R} \cap \vec{S} = \emptyset \ \& \ \vec{R} \in \vec{S} \wedge \vec{S} \notin \vec{R} <_{\text{ASPECT}} \vec{R} \in \vec{S} \ \& \ \vec{V} \rightarrow [\text{A},(\vec{V})] = [\text{B},(\vec{R})] \wedge [\text{B},(\vec{V})] = [\text{B},(\vec{S})] \ \& \ [\text{M},(\vec{V})] \leq 24\text{h} \ \& \ \text{E} (\vec{E}/\vec{E}/\vec{E}) \in \vec{R} \wedge \vec{R} \notin \text{E} (\vec{E}/\vec{E}/\vec{E}) \ \& \ \text{E} (\vec{E}/\vec{E}/\vec{E}) \neq \vec{R} <_{\text{AKTIONSART}} \text{E} = [\text{BECOME} + \text{LEFT\_00} (\% \text{PEDRO\_00}_{\text{Theme}})] >>>$$

An interlingua that builds upon the model proposed here plus language-specific linking rules would allow an NLP system such as FunGramKB, through its CLSs, to encode the temporal properties of utterances in virtually any language and, in turn, correctly interpret the utterances with their temporal characteristics. This would be greatly advantageous for search engines and automatic translation systems, among others.

<sup>8</sup> However, see footnote 2.

## 8. CONCLUSIONS AND LINES OF FURTHER RESEARCH

In this article we have described a mathematical model for the representation of the temporal properties of utterances in a four-dimensional space by means of mathematical objects. This model is language independent and aims to be universal. We have argued that the temporal properties conveyed by an utterance can be dealt with by means of three different and independent systems: tense—past, present and future—aspect—perfectivity, imperfectivity and progressivity—and *Aktionsart*—dynamicity, telicity and duration. Finally, we have proposed the integration of this model into the CLS structures of FunGramKB, which along with language-specific linking rules, result in an interlingua in which the temporal properties of the utterances of any language can be defined. This would significantly increase the accuracy of applications such as search engines and automatic translation systems when dealing with natural language.

There are two important issues that remain open for further research: the interaction of the different temporal systems with one another—for example, the interaction of progressivity (aspect) and punctuality (*Aktionsart*) that results in the repetition of a punctual event—and the further development of the sets of linking rules for specific languages.<sup>9</sup>

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