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A Two-Level Semantics for French Expressions of Motion

Pierre Sablayrolles

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Deutsches Forschungszentrum für Künstliche Intelligenz GmbH

Postfach 20 80
D-6750 Kaiserslautern, FRG
Tel.: (+49 631) 205-3211/13
Fax: (+49 631) 205-3210

Stuhlsatzenhausweg 3
D-6600 Saarbrücken 11, FRG
Tel.: (+49 681) 302-5252
Fax: (+49 681) 302-5341

Deutsches Forschungszentrum für Künstliche Intelligenz

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Prof. Dr. Gerhard Barth
Director

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Pierre Sablayrolles

DFKI
German Research Center for AI
Stuhlsatzenhausweg 3
D-6600 Saarbrücken
Germany

sablay@dfki.uni-sb.de

IRIT
University Paul Sabatier
118 route de Narbonne
31062 Toulouse Cedex
France

sablay@irit.fr

Abstract

Developing suitable representations for formalizing time and space knowledge has always been of a great importance in Artificial Intelligence (AI) and cognitive science. We here present a new way to conjoin these two problems. From the linguistic study of motion (which is the best concept available to associate space and time at the lexical and phrase levels), realized by Laur (1991), we construct a system to represent the spatio-temporal semantics of motion. This linguistic analysis consists of a semantic classification of the French motion verbs and spatial prepositions and of the elaboration of compositional rules between the semantic classes of these verbs and these prepositions. Our system, based on a two-level semantics representation, allows to formally represent the results drawn by the linguistic part and to perform some kind of natural spatio-temporal reasoning.

CONTENTS

1. INTRODUCTION

Formalizing time and space knowledge is an important topic in AI and cognitive science. The work we present here takes place in the framework of the study of formal semantics of natural language. Recent studies (cf. Vieu 1991, Aurnague 1991) have shown that space, as it is represented and described in natural language, is strongly linked to time. Here, we are interested in the way of formalizing spatial cognitive concepts as they are revealed by natural language, ie. by also considering their temporal dimension. This approach, consisting of a joint study of spatial and temporal aspects, is based on a primordial fundamental principle : space constitutes in itself a trace of time, ie. time can be viewed through space. We have then looked for a concept in natural language which as clearly as possible expresses its temporal and spatial aspects and their interrelation. The concept of motion seems to be a very good candidate because it allows for the description of spatial places following each other in time. Two major components are used to build expressions of motion : motion verbs and spatial prepositions. Our study starts from results of a linguistic study (Laur 1991) on expressions of motion in French, which consists of a semantic classification of motion verbs and spatial prepositions and of the elaboration of compositional rules between the semantic classes of these verbs and prepositions. The aim of our study is the elaboration of a formal representational system for the spatial and temporal semantics of expressions of motion. To be of some interest, such a system has obviously to possess inferential capacities. Furthermore, the results of this spatio-temporal reasoning must of course be in accordance with deductions humans make when faced with the same knowledge. For a long time, spatio-temporal reasoning has been one of the main centers of interest in AI, but still remains difficult to handle. It seems of considerable interest, for AI in general, to tackle this problem with another approach than the traditional ones, ie. from linguistic studies and by considering "natural" spatio-temporal reasoning. It is also of considerable interest for the interdisciplinary study of the semantics of natural language.

The linguistic study (Laur 1991) we have chosen to base our work on consists of two classifications (one for motion verbs and one for spatial prepositions) of spatial and temporal semantic criteria. The originality of this work is that motion verbs, respectively spatial prepositions, have been studied separately, independently of any context. These classifications have thus been realized on only pure intrinsic features. It is only in a second step that the semantics of the combination of one verb and one preposition in an expression of motion is built up by means of compositional rules on classes of verbs and classes of prepositions. This study has also been made with the concern to use its results in a formal representational system. The part concerning the classification of French motion verbs is in the spirit of the works realized by Boons (1985; 1987). It also makes use of a study realized by Guillet (1990), though this latter is restricted to syntactic aspects. For the classification of French spatial prepositions, it follows the works of Aurnague (1991), Borillo A. (1988; 1990; 1991) and Vandeloise (1986; 1987), realized on the static aspect of the relation of localization in French. Laur has extended these approaches also to the dynamic aspect.

However, for the formal semantics of space, unlike the study of the semantics of time, it does not exist traditional theoretical frameworks (as the approaches by means of points (Bestougeff & Ligozat 1989), intervals (Allen 1983) or events (Kamp 1979)). Although some attemps have been made to extend, for example, the temporal logic of Allen to the qualitative representation of space (Güsgen 1989;1990), they unfortunately result in complex and not very cognitive representations (cf. §3.3). We here prefer to take a different approach, close to the concept of *"histories"* of Hayes (1978), who is the first to use quadri-dimensional basic objects (the "histories") for the description of space. It is a way to see space through the evolution of the objects and the events. It is then particularly well adapted to the fundamental principle we have decided to follow. It in addition allows to construct space in a relational way (which is the way commonly used in natural language). Following Vieu (1991), we consider space as an abstract object built from relations between entities. Since they occur during a given event, we construct a space dependent on time. By considering the space in its temporal continuity, we finally obtain a space-time. A formal structure for this space-time has been built by Vieu (1991), from an adaptation of the calculus of individuals of Clarke (1981; 1985). We use this structure as the basis for our logical system of representation of the spatio-temporal semantics of expressions of motion (cf. §3.5).

In this paper, we present in detail the linguistic study of Laur (1991) on motion verbs (§2.2), spatial prepositions (§2.3) and their semantic combinations (§2.4). Its results lead to the elaboration of a two-level semantics (§3.1), which appears to be a very fruitful concept for spatio-temporal reasoning (§3.7). We show that the linguistic study has revealed the existence of typical places and the correlation between the links among these places and the semantics of the expression of motion in which they occur. We introduce some tools, namely some markers, in order to catch these typical places at the representational level (§3.2). Expressing the links between typical places then amounts to represent links between our markers using formal relations. We consequently need a formalism, which must satisfy the two following constraints : on the one hand, it has to provide an adequate set of relations; on the other hand, it has to be based on an ontology as suitable as possible to human conceptualization of space, time and motion (§3.3). We present and discuss currently used formalisms and look in detail which properties an adequate one needs to have (§3.3). The closer one to our concern is the Mereology of Clarke (§3.4). It is unfortunately not completely adequate and some modifications and extensions are required (§3.5). We propose a representation of spatial entities and temporal events as spatio-temporal individuals, defined by both spatial and temporal constraints. This also appears to have very important consequences in providing the possibility to assure spatio-temporal continuity, which is crucial in performing spatio-temporal reasoning (§3.7). Through an example we introduce representational rules for both levels of semantics (§3.6). We finally provide an example showing how these formal representations can be easily and shortly manipulated, and, therefore, how they are interesting for performing natural spatio-temporal reasoning (§3.7).

2. A LINGUISTIC APPROACH TOWARDS THE SEMANTICS OF EXPRESSIONS OF MOTION

2.1. Introduction

2.1.1 Objectives

The linguistic study realized by Laur (1991) tries to establish the precise role of motion verbs and spatial prepositions in expressions of motion. The methodology followed consists of bringing out pure intrinsic characteristics of each of these components, out of any context and independently of any combination of verb-preposition. Classifications are then elaborated on spatial and temporal semantic criteria. It is only in a second time that the semantics of an expression of motion is built up, by means of compositional rules, from the semantic classes of the verb and the preposition involved in the considered expression.

2.1.2 Limits of the Linguistic Study

This study has been realized in the French language. From a syntactic point of view, it has limited itself to the locative structure given in example (1) below, where Nc denotes the subject, ie. the moving entity, Vdp a motion verb, L_Prep a spatial preposition or a prepositional phrase (cf. §2.3), and Ns the locative complement "interpreted" as a place. This kind of interpretation of course leads to a restriction of the semantic domain covered. All sentences corresponding to set phrases or metaphoric structures (as (2) and (3) for example) are not considered in this study.

(1) Nc Vdp L_Prep Ns
Jean est entré dans la maison John has come into the house
(2) *Courir à la catastrophe*
(3) *Monter en grade*

A last restriction concerns the tense of the verb. Laur has chosen to consider only the *passé composé* (present perfect) because its perfectiv aspect allows to avoid the interference of the aspectuality linked to the tense with the aspectuality linked to the polarity of the verbs (which is the only one this study want to grasp).

2.2. Semantic Classification of Motion Verbs

2.2.1 Some Definitions

Laur has classified only verbs which correspond to the definition of the verb of motion given by Boon (1987) : *"a verb of motion is a verb of movement which implies that a body moves from one place to another without any modification of its form or of its substance during the process"*.

(4) *Jean est arrivé* John has arrived
(5) *Jean est arrivé à Toulouse* John has arrived to Toulouse
(6) *Jean est arrivé de Toulouse* John has arrived from Toulouse

Each verb of motion suggests, implicitly, a place. In (4), even if no explicit place is given, unlike (5) and (6), we nevertheless understand that John arrives somewhere. This implicit place is called the **verbal space of reference**, **LRV** (in French : ***L****ieu de* ***R****éférence* ***V****erbal*). When an explicit place (Ns) is present in the expression of motion (like in (5) and (6)), it is not necessarily always in accordance with the LRV. We have a **relation of congruence** when Ns is in accordance with the LRV, as in (5) : John arrives somewhere, and he really does to Toulouse. Otherwise, we have **not a relation of congruence**, as in (6) : John arrives from somewhere (LRV) which is not Toulouse (Ns).

2.2.2 Spatial and Temporal Semantic Criteria

2.2.2.1 The First Criterion

This example (6) also shows the existence of different polarities. Following Boons (1985), the **aspectual polarity** constitutes a criterion for the classification of motion verbs. It is our first criterion. A verb is **initial** if it suggests an initial place (as *"partir"* (to leave), *"s´éloigner"* (to go away)), **medial** if it suggests a medial place (as *"passer"* (to go over), *"courir"* (to run), *"graviter"* (to revolve round)) or **final** if it suggests a final place (as *"arriver"* (to arrive), *"s´approcher"* (to approach)) (cf. fig. 1).

2.2.2.2 The Second Criterion

For some verbs (*"s´éloigner"*, *"s´approcher"*, *"courir"*, *"graviter"*), the moving entity stays during its whole motion on the same side of the LRV. Others (*"partir"*, *"arriver"*, *"passer"*) describe a moving entity which crosses the "frontier" of the LRV, at least one time, during its motion. This difference is used as the second criterion. For the former group we say that there is **no change of space of reference**; for the latter that there is **change of space of reference**.

2.2.2.3 The Third Criterion

A third criterion is introduced and concerns the **relation of localization** of the moving entity w.r.t. the LRV, during the phase of the motion corresponding to the polarity. This relation can be **internal** (as for *"partir"*, *"arriver"*, *"passer"*, *"courir"*) or **external** (*"s´éloigner"*, *"s´approcher"*, *"graviter"*).

We would like to provide some motivations for the necessity of this third criterion : the classes of medial verbs with no change of space of reference indeed seem to group together verbs of different essence (for example *"courir"* vs. *"graviter"*). They consequently have to be distinguished. If verbs like *"graviter"* seem to be coherent with the other verbs with no change of space of reference (for example *"s´approcher"*, *"s´éloigner"*), verbs like *"courir"* seem to keep themselves to themselves.

A first temptation could consist in putting them into a kind of "neutral group" for which we simply wait to know the group of the preposition we combine with, to deduce the type of the resulting VP. But this is at variance with the chosen methodology, which consists in establishing intrinsic classifications, in an independent way of any combination or context.

The choice to introduce this third criterion is justified by the methodology and in fact does not just allow the distinction between verbs like *"courir"* and verbs like *"graviter"*, but also the elaboration of a mould of what can be conceived as relations between the different concepts of motion (cf §3.1, especially the note 3).

2.2.3 The Classification of French Motion Verbs

Using these three criteria, a classification in seven non-empty groups of the French motion verbs is proposed in fig. 1.

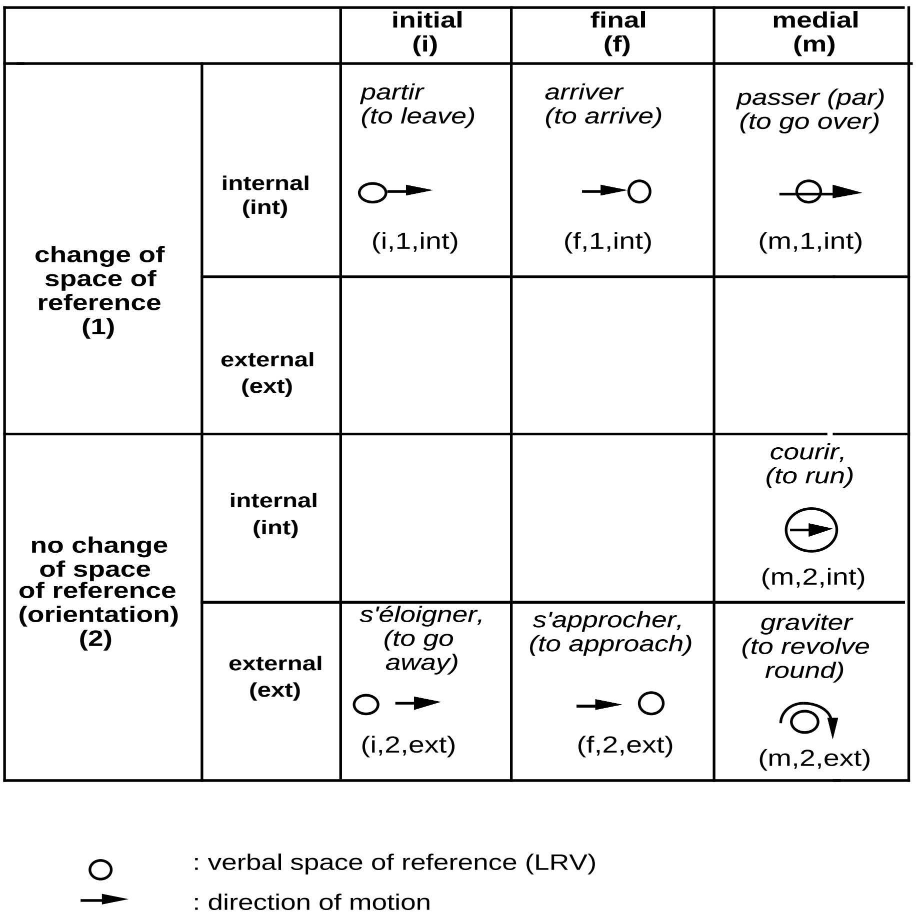

Figure 1 : classification of French motion verbs

2.3. Semantic Classification of Spatial Prepositions

2.3.1 Two Main Groups of Spatial Prepositions

Prepositions, simple or complex (ie. prepositions or prepositional phrases) can be separated in two main groups.

In the first group, prepositions are called **positional prepositions** since they just describe a relation of localization. According to the criteria of **relation of localization** establishes in §2.2, we can here also have **internal** (for example *"dans"* (in)) and **external** (*"en face de"* (in front of)) prepositions (cf. fig. 2).

In the second group, prepositions are called **directional prepositions** since, in addition of a relation of localization, they also suggest an obligatory direction the moving entity has to use in order to access[1] to the place introduced by these prepositions. We consequently use for them not only the criterion of **relation of localization** (**interne**; **externe**), but also the criterion of **aspectual polarity** (**initial**; **medial**; **final**).

2.3.2 The Classification of French Spatial Prepositions

In figure 2, a classification in eight groups of the French spatial prepositions is proposed.

[1] "access to" has to be understood in a broad sense; indeed, if for verbs like *"arriver"* (to arrive) it is really an "access to" the place, for verbs like *"partir"* (to leave) it is a "leaving of" the place, or for verbs like *"passer"* (to go over) it is a "cross of" the place, and so on.

		internal (int)	**external (ext)**
positional		*dans* *(in)* *sur* *(on)*	*en face de* *(in front of)* *derrière* *(behind)*
directional	**initial (i)**	*de* *(from)* *de chez* *(from at)*	*de derrière* *(from behind)*
	final (f)	*jusqu'à* *(as)*	*vers* *(towards)* *jusque sous* *(as far as under)*
	medial (m)	*par* *(through)*	*autour de* *(round)* *par dessus* *(through above)*

Figure 2 : classification of French spatial prepositions

2.4. Compositional Rules Between Motion Verbs and Spatial Prepositions

2.4.1 Type of Motion

Now that we have intrinsic classifications of motion verbs and spatial prepositions, compositional rules are expressed. The result of a combination is represented in what is called a **type of motion** by means of the three criteria defined in §2.2. Thus, twelve different types of motion are defined. In order to present clear illustrations of these rules, we propose the following semi-formal notations (that will also be used in part 3) :

Vdp (I,1,int)	represents the group of motion verbs characterized by the values I, 1 and int[2] to its three criteria;
L_Prep (int)	represents the group of positional prepositions with an internal relation of localization;
L_Prep (I,int)	represents the group of directional prepositions characterized by the values I and int to its two criteria;
motion (I,1,int)	represents the type of motion characterized by the values I, 1 and int.

[2] the same with all the other possible values for each criterion.

2.4.2 Combinational Rules

Rule 1 : for the combination of a positional preposition with :

a) a medial or final verb :

the verb determines the aspectual polarity and the change of space of reference of the resulted type of motion;

the preposition determines the relation of localization (see (7))

b) an initial or medial internal verb :

the same as in a), except that the aspectual polarity of the type of motion here is always final (see (8))

Rule 2 : for the combination of a directional preposition with a motion verb :

the verb determines only the change of space of reference;

the preposition determines the aspectual polarity and the relation of localization (see (9)).

(7) *Jean est arrivé à Toulouse*

John has arrived to Toulouse

Vdp (**F**,**1**,int) + L_Prep (**int**) => motion (**F**,**1**,**int**)

(8) *Jean est sorti dans le jardin*

John has gone out into the garden

Vdp (I,**1**,int) + L_Prep (**int**) => motion (**F**,**1**,**int**)

(9) *Jean s´est enfui par le jardin*

John has run away by the garden

Vdp (I,**1**,int) + L_Prep (**M**,**1**) => motion (**M**,**1**,**int**)

(10)*La balle a roulé sous la table*

The ball has rolled under the table

Vdp (**M**,**1**,int) + L_Prep (**ext**) => motion (**M**,**1**,**ext**) (rule 1-a)

Vdp (M,**1**,int) + L_Prep (**ext**) => motion (**F**,**1**,**ext**) (rule 1-b)

2.4.3 The Double Interpretation for Medial Internal Verbs

We would like to point out that in the case of a combination of a positional preposition with a medial internal verb, both rules 1-a and 1-b can be applied. However, this is normal, since we have two possible interpretations in this case in natural language. In (10), the application of the rule 1-a corresponds to a medial interpretation : the ball is already under the table before the motion and stays there through the whole motion. The application of the rule 1-b leads to the final interpretation : the ball is not under the table when it begins its motion; but its motion is such that it goes (rolling) under the table.

2.5 Conclusion

To achieve the presentation of this study, we could resume saying that the semantics of an expression of motion does not result from a simple "addition" of the semantics of the verb and the preposition involved, but, all on the contrary, from a complex interrelation.

3. A FORMAL REPRESENTATION

3.1 A Two-Level Semantics

3.1.1 Do the Types of Motion Cover All Theoretical Combinations ?

We have seen that a type of motion can be expressed using the three criteria defined in §2.2.2. From a pure combinatorial point of view of the different possible values for each criterion, we obtain twelve different types of motion, namely :

motion (I,1,int)	motion (M,1,int)	motion (F,1,int)
motion (I,1,ext)	motion (M,1,ext)	motion (F,1,ext)
motion (I,2,int)	motion (M,2,int)	motion (F,2,int)
motion (I,2,ext)	motion (M,2,ext)	motion (F,2,ext)

A type of motion is obtained by the application of compositional rules (cf. §2.4) between a group of verbs and a group of prepositions. For the French language, the linguistic analysis of Laur has revealed the existence of seven non-empty groups of verbs and eight groups of prepositions. We should therefore have, from a pure theoretical combinatorial point of view, 56 different possible combinations. It is nevertheless true that combinations are not generally free in natural languages. For example, to continue our discussion on the French language, a study of these combinations shows (cf. fig. 13 in §3.6) that only 34 of the 56 theoretical combinations are in fact linguistically accepted in the French language[3]. We consequently have only 12 types of motion for representing 34 different combinations. For example, 9 different combinations lead to the type of motion : motion (F,1,int), namely :

by application of the compositional rule 1a)	:	Vdp (F,1,int) + L_Prep (int)	(a)
by application of the compositional rule 1b)	:	Vdp (I,1,int) + L_Prep (int)	(b)
		Vdp (M,1,int) + L_Prep (int)	(c)
by application of the compositional rule 2)	:	Vdp (I,1,int) + L_Prep (F,int)	(d)
		Vdp (I,1,ext) + L_Prep (F,int)	(e)
		Vdp (M,1,int) + L_Prep (F,int)	(f)
		Vdp (M,1,ext) + L_Prep (F,int)	(g)
		Vdp (F,1,int) + L_Prep (F,int)	(h)
		Vdp (F,1,ext) + L_Prep (F,int)	(i)

3.1.2 The Answer is 'NO'

A detailed analyse of this phenomenon leads to the conclusion that a classification by means of types of motion is not a sufficient fine-grained classification, in the sense that a type of motion groups together motions which are not exactly the same, ie. which do not express exactly the same semantics.

We can use the previous example to illustrate this. We propose to compare three of the above listed combinations which lead to the same type of motion : motion (F,1,int). The values of the three criteria of this type of motion explain that it groups together motions which have a final polarity, a change of space of reference during the motion (ie. the moving entity

[3]This difference is of course specific to the French language. Other studies on different languages would certainly bring different results, for the number of linguistically accepted combinations, but also for the number of non-empty groups of verbs and prepositions. But the linguistic framework used here seems well adequate to serve as a common structure for multi-lingual studies and to be at the basis of extremely interesting and fruitful comparative linguistic studies, we hope for a realization in a near future.

does not stay during the whole motion inside, respectively outside, the space of reference), and an internal localization at the end of the motion w.r.t. the final place.

In the case of the combination (b), which can be illustrated in natural language by, for example, *"partir dans"* ("to leave in"), we in addition have an insistance on the information that the moving entity starts from a place (the LRV).

This is obviously not the case for the combination (c), for example, *"passer dans"* ("to go over in"), where the insistance is on the information that the moving entity goes through a place (LRV) during its motion.

The same holds for the combination (a), for example, *"arriver dans"* ("to arrive into"), where we have a relation of congruence between the verb and the preposition (each introduces a final place).

This illustration also allows to show that a type of motion groups together motions which in fact differ only by the kind of relation which stands between the LRV and the Ns. This relation depends on the fact that the places, respectively refered by the LRV and the Ns, are initial, medial or final places. It can consequently be deduced from the group of, respectively, the verb and the preposition. More precisely, from the value of their polarity criterion.

3.1.3 A Solution : a Two-Level Semantics

In order to describe more precisely the spatio-temporal semantics of natural expressions of motion, we are then led to proceed in two steps : the computation of the type of motion, and the specification of the relation between the LRV and the Ns.

One normal temptation at the representational level could consist in computing these two steps and building a global representation of both steps. We have here chosen another approach. We define a two-level semantics.

The **first level**, or **imprecise level**, describes the relations between the moving entity and, respectively, the LRV and the Ns (this corresponds at the linguistic level to the type of motion).

The **second level**, or **precise level**, includes the first one and makes it fully precise by adding the relation which stands between the LRV and the Ns.

3.1.4 Advantages of Such a Solution

We argue that this approach is more fruitful, and we show at the inferential level (§3.7) that we can realize natural inferences (at least some kinds of them) using a spatio-temporal reasoning only based on the first level semantics representation. This is an important trump, especially from a computational point of view[4], where it means that we can perform some kinds of natural inferences working on a reduced set of relations (w.r.t. the complete set corresponding to the precise level), ie. having both a smaller size of the handled data and a shorter execution time of the reasoning processes.

3.2 A Set of Markers

3.2.1 Introduction

The linguistic study of Laur has revealed the essential role played by typical places, present[5] in an expression of motion, in the elaboration of its semantics. In fact, we have a strong correlation between the spatial and temporal links between these typical places and the spatial and temporal semantics of the expression of motion in which they occur. At the representational level, to formalize this semantics then amounts to represent these links formally. Here, we have made the choice to use a set of typed markers to catch, at the representational level, these places brought out at the level of the linguistic analysis. An advantage of this approach is to allow to treat motion in a more general way, ie. not in a way strongly dependent on particular examples or on only few preselected verbs and prepositions. We are thus able to enonciate general rules, directly at the level of these markers, independently of any underlying concrete expression of motion.

We also need a set of formal relations in order to represent spatial and temporal links between our markers. We discuss in §3.3 what kind of formalism we are looking for. A good formalism for this work must indeed not only provide an adequate set of spatial and temporal relations, but it must also be based on an ontology as suitable as possible to human beings´ conceptualization of space, time and motion (in fact revealed through natural language expressions). We come back to this point in the next paragraph where different formalisms are presented and discussed.

Before doing this, we would like to introduce and define our set of markers.

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[4]Even if we do not treat the computational level in this paper, it nevertheless remains an important level which has to be taken into account for the selection of the most adequate approach at the other levels.

[5]Explicitly in the case of the place refered by the Ns, or implicitly for the one refered by the LRV.

3.2.2 Some Markers to Catch Typical Places

3.2.2.1 A Syntactic Distinction for Typical Places

For this, let us return to places. The linguistic analysis of Laur has shown that places can be introduced in an expression of motion by two different means.

The first one is "as" a LRV. In fact, verbs do not introduce themselves directly places, but rather create a kind of phenomenon similar to anaphora, which allows to match the LRV (the implicit place suggested by the verb) with a place introduced previously or further in the analysed discourse or with a context-dependent place.

The second means is as a Ns, preceded by a spatial preposition[6]. This distinction in fact corresponds to a syntactic one.

3.2.2.2 A Semantic Distinction for Typical Places

A more precise analyse of the results brought by this linguistic study gives evidence to the existence of a semantic distinction too, between **real places** and **places of reference**, each of them having either an initial, medial or final polarity. The following examples illustrate this semantic distinction.

(11)*Jean est passé de la maison dans la rue par le jardin*

John went from the house into the street by the garden

(12)*Paul s´est éloigné de la maison*

Paul has gone away from the house

(13)*Paul a longé le mur*

Paul has gone along the wall

(14)*Paul s´est rapproché de la voiture*

Paul has approached the car

In (11), *"maison"*, *"rue"* and *"jardin"* are, respectively, a real initial, a real final and a real medial place. The house is indeed the place in which John is at the beginning of his motion. It really represents the place of John at the beginning of his motion. Likewise for the street and the garden, relatively to, respectively, the end and the medial part of the motion of John.

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[6]Other means are of course possible. For example as a direct object : *"traverser la rivière"* ("to cross the river"). This, however, does not belong to the syntactic domain covered by the linguistic study of Laur.

On the contrary, in (13) the wall can absolutely not be considered as a real medial place. It is obvious that during the medial part of his motion, Paul is not inside the wall. The wall cannot represent the place of Paul during the medial part, but rather represents a medial place of reference. Likewise for (12) and (14) with, respectively, the house which has to be considered as an initial place of reference and the car as a final place of reference.

3.2.2.3 The 6 Markers

We define six markers (as shown in figure 3), each of them corresponding to one of these six different types of places. For our previous examples, we then have the following correspondances : in (11), we can match[7] LI and *"maison"*, LM and *"jardin"*, LF and *"rue"*, in (12), RLI and *"maison"*, in (13), RLM and *"mur"*, in (14), RLF and *"voiture"*.

	Initial Aspect	Medial Aspect	Final Aspect
Real Place	LI	LM	LF
Place of reference	RLI	RLM	RLF

Figure 3 : a set of markers for typical places

3.2.3 Temporal Aspect Captured Through Spatial Aspect

We use these markers for catching at the representational level spatial places brought out by the linguistic level. By the way we have defined them, it seems obvious that they catch more than the spatial aspect of these places; the temporal aspect, corresponding to the role they play during the motion, is also captured. We would like to discuss a little more this temporal aspect, and, finally, to introduce three additional markers.

[7]The matching is here presented in a non-formal and very intuitive way. We are in fact able to perform it automatically from the calculation of the type of the corresponding motion and the application of representational rules (cf. §3.6).

3.2.3.1 'Normal' versus 'Global' Duration

When people dealing with motions want to talk about their duration, they generally implicitly make reference to what we will here call the **normal duration** of a motion. By normal duration, we understand the temporal length which begins when the motion starts and which ends when the motion finishes.

(15)*Jean est sur la pelouse. Il entre dans la maison. Maintenant il est dans la maison*

John is on the lawn. He enters into the house. Now he is in the house

(16)*Jean sort de la maison dans le jardin. Puis il passe dans la rue et rentre chez l´épicier*

John goes out of the house into the garden. Then he goes into the street and enters the grocer´s

In the case of a motion surrounded by two states, as in (15), the possibility to distinguish static and dynamic temporal phases allows an easy determination of the two boundaries (start and end) of the normal duration of the motion. This is unfortunately not the case when several motions are following each other.

In (16) for example, it becomes extremely difficult to define precisely what we think about when we talk about the normal duration of the motion described by the first proposition of the second sentence (*"Puis il passe dans la rue"*). It really seems to be a subjective choice : one can understand that John stays static for a while in the garden between the first two motions or not. Anyway, we do not know where and when John stays static in the garden, if he stays static, nor the path he follows (he can go ten times round inside the garden before going out into the street). But all this is extrapolation and cannot reasonably be inferred by a system from the knowledge of just the three sentences of (16).

To avoid this difficult problem, we define another kind of duration for a motion. We call it a **global duration** and define it, using the markers we have previously introduced, as follows : the global duration starts when the moving entity enters into the place refered as the real initial place (marker LI), and finishes when the moving entity goes out of the place refered as the real final place (marker LF). We have called it global duration because it includes the normal duration and it is consequently more global.

In (15), the two states which surround the motion are now included in the global duration.

If we take again our example concerning the second motion of (16), we have, for this second motion, the marker LI associated with *"jardin"* and LF with *"rue"*. We can then precisely define the global duration of this second motion, noted *stretch2* in fig. 4. We thus define in a simple way a global duration for each motion[8] (cf. fig. 4).

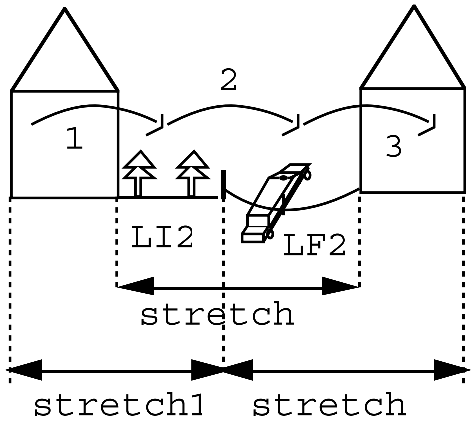


Figure 4 : graphical illustration of example (16)

3.2.3.2 Advantages of the Global Duration

With the definition of a global duration we have given, we obtain an overlap of two global durations corresponding to two motions immediatly next to another. Doing so, we do not construct the temporal structure of a text describing successive motions as an ordered list of normal durations, in which two successive durations can only meet or be separated by states, but as an ordered list of global durations, in which two successive[9] durations always overlap. In our system, states are included in the global duration, and therefore, we always obtain an overlap of the global duration of two successive motions even if they are separated by many states.

We would like to point out the advantage of such a representation; and we consider this not only as an advantage, but also as a necessary property for the inferential level. This overlap indeed insures the spatial and temporal continuity of all the entities which occur in two successive motions.

---

[8]For the first motion, respectively the last motion, described by the text to analyse, the moving entity does not enter into the LI of the first motion (it is in fact already inside when the text begins), respectively go out of the LF of the last motion (it is inside the LF when the text finishes, and, consequently, stays inside). In order to define the global duration of the first and last motion of the text, we use the time of beginning of the text, respectively the time of ending, as the beginning of the global duration of the first motion, repectively the end of the global duration of the last motion.

[9]In fact the two motions corresponding to these two global durations are successive.

To illustrate this, we can use our example (16). The overlap between the global duration of the first and the second motion insures that the moving entity of these two motions is really the same *"Jean"*, and that the final real place (*"jardin"*) in which *"Jean"* arrives at the end of the first motion is really the same as the place from which he goes out at the beginning of the second motion.

This spatial and temporal continuity of all the entities which occur in two successive motions is a primordial prerequisite to the realization of inferences (cf. §3.7).

3.2.3.3 Three Additional Markers

To close this section, we define three new markers, purely temporal, which follow from the definition of the global duration : **ti**, **tm** and **tf**, which represent the temporal length during which the moving entity is inside the real initial (marker LI), real medial (marker LM) and real final (marker LF) place, respectively.

We find them again in §3.6 and §3.7.

3.3 Motivation for the Formalism

3.3.1 Motivations

The six markers (LI, LM, LF, RLI, RLM and RLF) are used to catch at the representational level the typical places brought out at the linguistic level. To represent spatial and temporal links between these places, we need, at the representational level, a set of formal relations to be applied between our markers.

As we have said in the previous paragraph, the formalism we are looking for has to fulfil the two following conditions : it has to provide us with an adequate set of relations (by adequate we mean a set of relations allowing us to represent between our markers the links revealed at the linguistic level between the typical places, ie. the spatial and temporal semantics of the expression of motion), and it has to be based on an ontology as suitable as possible to human beings´ conceptualization of space, time and motion.

Why do we impose such conditions ?

The first one seems quite obvious. We indeed want to represent formally the semantics of expressions of motion that has been elaborated at the linguistic level. We thus need a formalism with which we can do it, as faithful as possible.

The second condition requires some explanations. Natural language is one of the vectors human beings use to exteriorize complex internal representations they have in mind. Representations of motions, for example, involve mental conceptualizations of space, time and motion. Our claim is that the way human beings use natural language to describe motions is strongly dependent on these conceptualizations, ie. expressions of motion in natural language reveal, unfortunately only partly, how human beings conceptualize space, time and motion. The use of a formalism whose ontology is as suitable as possible to these conceptualizations is an essential step towards the obtention of a formal representation of the spatial and temporal semantics of expressions of motion, which shall be as faithful as possible.

3.3.2 State of the Art (1)

3.3.2.1 Last Trends

Studies that have been considered and doing the last year have shown that cognitive concepts about space and time are qualitative in nature (cf., for example, Allen (1983) and Freksa (1990)). This is particularly obvious, for example, in visual acquisition of spatial knowledge and in natural language communications about spatial and temporal concepts.

When quantitative representational systems must predefine one (or a few) fixed granularity of their units, qualitative representational systems, more adequate because independent of specific values, allow in each context (granularity generally depends on context) for the choice of the exact required granularity, for both space and time.

In addition, spatial and temporal relationships used in natural language are imprecise and sometimes incomplete; qualitative representational systems allow to deal with this kind of relationships in an easy and natural way.

At least, qualitative representations are easily and shortly manipulable and consequently very efficient for performing spatial and/or temporal inferences and solving spatial and/or temporal problems (cf. Freksa 1990).

The second important point, revealed in recent studies, is that space, as it is represented and described by natural languages, is a relational space, but also a space strongly linked to time (cf. Vieu (1991) and Aurnague (1991)). A spatial relation between two entities is taken at a given moment, identical for both entities. Therefore, human beings model cognitive spatial concepts by relational representations of the relationships between spatial entities. However, they consider these entities in a way different from a pure spatial way, in order to take into account also the temporal component which is linked to them.

Thus, we are interested in the way to formalize spatial cognitive concepts as they are revealed by natural language, ie. by also considering their temporal dimension. Unlike the study of the semantics of time, for the formal semantics of space, traditional theoretical frameworks do not exist.

In the following, we present and discuss some of the most important existing formalisms.

3.3.2.2 The Qualitative Time Representation of Allen

The most important and well known formalism, which has influenced many other works, is the qualitative representation of time of Allen (1983 ; 1985).

It is a time theory based on a structure of intervals from a unique primitive relation : MEET. From this primitive, twelve other relations (fig. 5) are defined, such that the link between any two temporal intervals can always be described by one of these relations or a disjonction of them. These thirteen relations can be seen as basic relations. They are indeed mutually exclusive, ie. if one relation holds between two intervals, then none of the twelve others can hold between these two intervals.

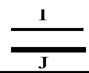
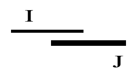
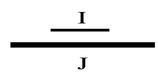
relation	définition	abréviation	inverse	exemple
I meets J	< *relation primitive* >	m	mi	
I before J	∃ K / I m K m J	<	>	
I equal J	∃ K,L / (K m I m L) ∧ (K m J m L)	=	=	
I overlaps J	∃ A,B,C,D,E / (A m I m D m E) ∧ (A m B m J m E) ∧ (B m C m D)	o	oi	
I starts J	∃ A,B,C / (A m I m B m C) ∧ (A m J m C)	s	si	
I finishes J	∃ A,B,C / (Am B m I m C) ∧ (A m J m C)	f	fi	
I during J	∃ A,B,C,D / (A m B m I m C m D) ∧ (A m J m D)	d	di	

Figure 5 : Allens´ relations

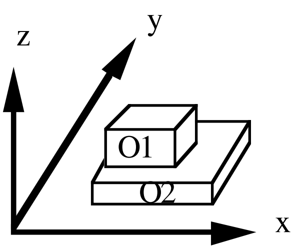
3.3.2.3 Güsgen : an Extension of Allen's Formalism to Space

In order to generalize this system to space, some studies have been realized, for example the one of Güsgen (1989 ; 1990).

The key idea of this work is to split spatial and temporal relationships between objects into components : left/right; front/rear; above/below; before/after. From the relations of Allen, he defines four basic relations (see fig. 6 for the component left/right). He then represents relationships between two objects by means of (set of) tuples of basic relations (see fig. 7 for a simple case).

relationshi	**symbo**	**symbol for**	**picture**
O1 left of O2	<	>	O1 O2
O1 attached to O2	≤	≥	O1 O2
O1 overlapping O2	<=	=>	O1 O2
O1 inside O2	⊏	⊐	O1 O2

Figure 6 : Güsgen´s relations for the left/right component



O1 (⊏ , ⊐ , ⩾) O2

Figure 7 : simple use of Güsgen´s relations

We must say about this work that it is unfortunately not at all a cognitive representational system.

Human beings do not really describe spatial relationships by using cartesian tuples of relations, each describing the link between intervals on one of the three cartesian axes.

In addition, this system can only treat parallelepipeds, all oriented in the same way. In the case of objects with undetermined shape, even the consideration of the smallest surrounding rectangle is not sufficient because a relation of contact, overlap or inclusion between the two surrounding rectangles is not always the same as the one between the two objects, and vice versa.

At least, it is not possible with this system to take into account intrinsic interpretations, commonly used in natural language.

3.3.3 Additional Motivations

We are obviously looking for a more cognitive formalism. It is in fact the formalization of cognitive concepts about space which seems to be really difficult and complex. Therefore, before going further, we would like to discuss more deeply what looks like human beings´ conceptualization of space.

We try, in the three following points, to give some elements of an answer.

3.3.3.1 Space is Regarded as a Whole

Firstly, it seems that space is regarded as a whole. Indeed, if some prepositions in natural language, like "on" or "in front of" for example, show that human beings use natural referential axis (for example the axis of gravity in the case of "on") or artificial referential axis, built from referential objects (as in the case of "in front of"), other prepositions, such as "near", "close to", clearly show that human beings have the faculty to manipulate and describe space without using any referential axis, ie. considering space simply as a whole.

3.3.3.2 Objects are Basic Entities

Secondly, it seems that space is filled up by objects considered as basic entities. We commonly speak about things like "the book is on the table" without specifying (and even often without knowing) more about these objects. In particular their precise shape (the book can be open or closed), their size or relative size, their structure (the table can have a big hole or a leg missing). That means that we cannot assume basic smaller elements (such as the basic well-known "points") to be used by compositional arrangements to build the objects we refer to. All on the contrary, we use these objects directly as basic spatial entities.

3.3.3.3 Space is Qualitative

Thirdly, it seems, from all we have said before, that space is described by expressing qualitative relationships directly between spatial entities.

3.3.4 State of the Art (2)

3.3.4.1 Mereology : its Definition

Studies in this direction are nevertheless not new, since Aristotle already studied in the IVth century BC the part-whole relationships. The first formalisation, by another means than the Set Theory, is however only appeared in 1927-1931, due to Lesniewski, under the name of Mereology[10]. Mereology can be characterized by the three following important points :

* it refuses the existence of individuals of an higher-order, and, in particular, the existence of the null-element (the equivalent of the empty set in the Set Theory);

* it is not based on a prerequisite Euclidian space, but on a space built by the entities and their interrelations as they are introduced;

* its basic elements are not the traditional points but (spatio-temporal) individuals.

3.3.4.2 Mereology : its Advantages

The first point is clearly in accordance with the cognitive conceptualization of space and time. The second one furnishes a good background for qualitative representations. The last one answers our last request concerning the description of space by means of qualitative relationships directly between spatial entities, which are considered as basic elements. But this last point goes further. It allows for basic elements of the system not only spatial entities but also spatio-temporal individuals, as defined in naïve physics by Hayes (1978 ; 1985a ; 1985b), ie. as the spatio-temporal piece described by each object and each event.

At the beginning of this paragraph, we have said that space, as natural language shows it, is strongly linked to time and that we would like to formalize spatial cognitive concepts as

[10]"Mereology" cames from two Greek words : "meros" which means "part, portion"; and "logos", which means "language, speech".

they are revealed by natural language, ie. by also considering their temporal dimension. It is now entirely possible in the framework of the Mereology.

3.3.4.3 Mereology(ies) : a Brief History

Before presenting in detail the relations proposed by the Mereology, we would like to make a brief point of history because different equivalent systems have been developped since Lesniewski.

These relations can all be derived from a unique primitive relation. Whereas the different systems developped are more or less equivalent w.r.t. the power of the proposed relations, they mainly differ by the choice of the primitive relation.

So, the system of Lesniewski (1927-1931) is based on the primitive relation PP, where PP(x,y) means "x is a proper part of y" (cf. fig. 8 for a graphical illustration[11]).

Tarski (1937) proposed a version based on the primitive relation P, where P(x,y) means that "x is a part of y".

Leonard & Goodman (1940) built, under the name of Calculus of Individuals, a version based on the primitive relation DR, where DR(x,y) means "x is discrete from y".

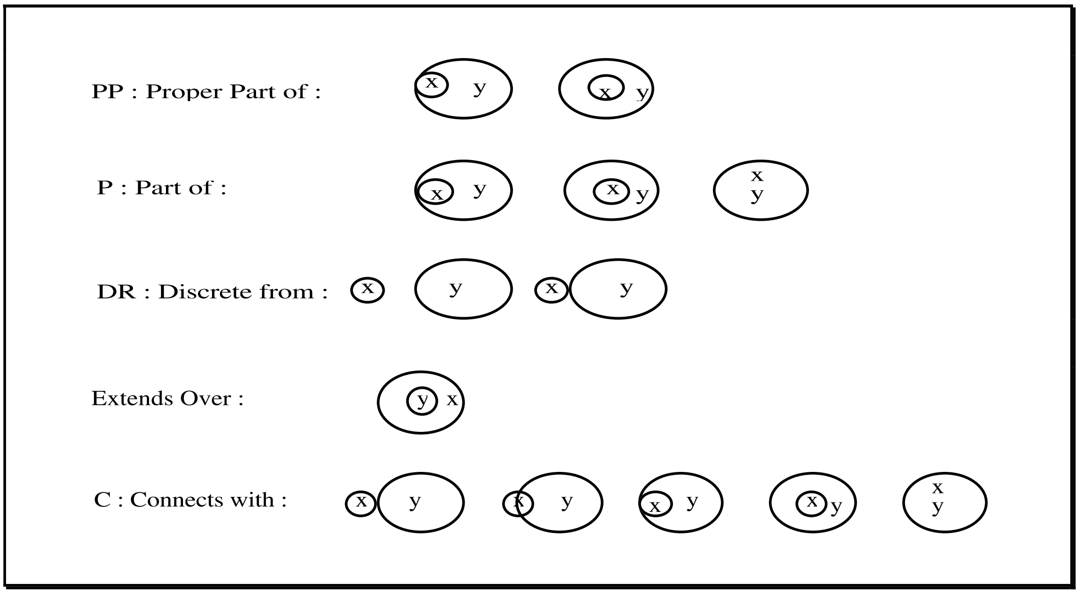


Figure 8 : the different primitives

[11]the graphical illustration here proposed followed the one introduced by Randell & Cohn (1985). Because of its two-dimensionality, it has as unique aim only to help the reader to "visualize" the relations we are talking about.

At the same time as Lesniewski, Whitehead (1919 ; 1920) built a theory based on the predicate "x extends over y", in fact a reciprocal relation to P (part of). In 1929, he published a revised version of his theory, based now on the predicate "x is extensionnally connected with y". Unfortunately, he has not formalized his theory, which was just based on "probable axioms" and "desirable theorems", without a lot of distinction, and which, in addition, contained a contradiction.

At least, Clarke (1981; 1985) took again the Whitehead´s theory, formalising it correctly, but using this time the relation C as primitive relation, where C(x,y) means that "x is connected with y". This relation had been introduced by Whitehead, but as a derived relation.

The system proposed by Clarke seems to be the best version of the Mereology for our work. In the next paragraph, we present the eight relations he defined. We then discuss what distinguishes the version of Clarke from the others and why we have chosen to use this one.

3.4. The Qualitative Space-Time Representation of Clarke

3.4.1 The Spatio-Temporal Relations of Clarke

From the primitive relation of connexion (C), Clarke (1981) formally defines eight other spatio-temporal relations (cf. fig. 9).

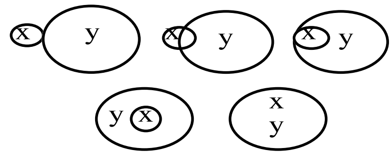
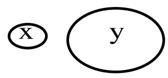
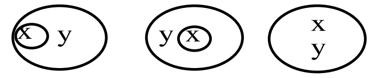
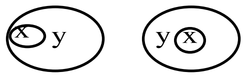
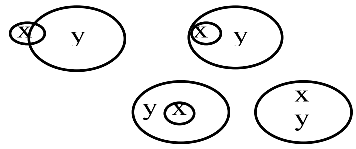
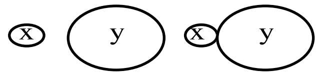
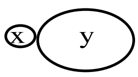
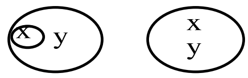
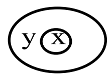
relation	name	définition	exemple
C(x,y)	connects with	< *relation primitive* >	
DC(x,y)	disconnected from	$\neg$ C(x,y)	
P(x,y)	part of	$\forall$z, [C(z,x)$\rightarrow$C(z,y)]	
PP(x,y)	proper part of	P(x,y) $\wedge \neg$ P(y,x)	
O(x,y)	overlaps	$\exists$z, [P(z,x)$\wedge$P(z,y)]	
DR(x,y)	discrete from	$\neg$ O(x,y)	
EC(x,y)	externally connected to	C(x,y) $\wedge \neg$ O(x,y)	
TP(x,y)	tangemtial part of	P(x,y) $\wedge$ $\exists$z, [EC(z,x)$\wedge$EC(z,y)]	
NTP(x,y)	nontangential part of	P(x,y) $\wedge$ $\neg\exists$z, [EC(z,x)$\wedge$EC(z,y)]	

Figure 9 : Clarke´s relations

3.4.2 The Particularities of the Version of Clarke

The system of Clarke is distinguishable from other versions of Mereology on the following points. Clarke dropped Whitehead´s assumption that individuals must be continuous. He also extends Whitehead´s theory, which dealed only with mereological aspects, by introducing quasi-boolean[12] and quasi-topological[13] operators. The most consequent difference is the choice of C as primitive relation. This allows him to establish a distinction between the overlap relation (O) and the connection relation (C), which leads to

[12]"quasi-boolean" because there is no null element, in the pure tradition of Mereology.
[13]"quasi-topological" because there is neither a null element, nor boundary elements.

the emergence of a new relation, a relation of external connection (EC) (cf. fig. 9 above). This relation turns to be of highest interest. With it, Clarke can ever since build a quasi-topology (1981) before defining the notion of point (1985). This give to his system a strong cognitive dimension. It is indeed very suitable to the way human beings conceptualize space. A point alone does not exist in space and we cannot refered it directly in natural language. When we want to talk about a particular point, we must use a set of concrete entities to construct it. For example, we can point a finger and say "the point at the end of my finger", or use referential entities like in "the corner of the table" (cf. Vieu 1991). As natural language reflects it, human beings in fact construct points from entities (that means a point is defined by a set of entities) and do not conceptualize entities as set of points. Clarke (1985) reconstructs the notion of point, by means of filter´s methods[14], as set of entities. The system of Clarke is consequently the most adequate formalism for our work.

3.4.3 A Lattice Structure

Just before using it, we would like to introduce six new relations that have been defined by Randell & Cohn[15] (1989) in order to obtain a set of relations with a lattice structure.

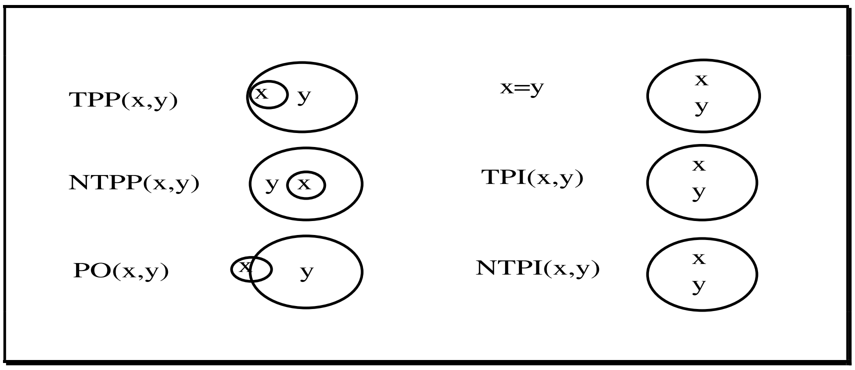


Figure 10 : additive relations of Randell & Cohn

[14]This is equivalent to the construction of instants from events for temporal theories (Kamp 1979; Bras 1990).

[15]The system defined by Randell & Cohn (1989) is based on a different ontology, w.r.t. the one of Clarke (introduction of a null-element; non use of second order variables, which leads to the consideration of points as primitive entities) which is less adequate for our work. We will therefore just add these new relations they have defined to the system of Clarke.

3.5. Some Extensions of the System of Clarke.

3.5.1 One Problem With the Formalism of Clarke

Although the system of Clarke is the best formalism we have found for our work, it is unfortunately not completely adequate, and needs some modifications. The problems came from the fact that there exists a difference between a spatio-temporal individual corresponding to a static[16] object and an individual corresponding to a dynamic one, namely the fact that the second has a certain motion w.r.t. the first. This distinction cannot be represented in the present version of the system of Clarke.

(17)*Jean entre dans la pièce*
John goes into the room
(18)*Jean sort de la pièce*
John goes out of the room

Let us consider sentences (17) and (18) as an illustration of this.

For more clarity in our purpose, we introduce some mnemotechnical names for the spatio-temporal individuals we are dealing with. Let us call J the spatio-temporal individual corresponding to *"Jean"* and P the spatio-temporal individual corresponding to *"pièce"*. In order to simplify the notations[17], we here consider J and P as in fact representing a temporal restriction of the spatio-temporal individuals corresponding respectively to *"Jean"* and *"pièce"*, restriction to the global length of the motion in which they occur.

In (17), John is outside the room during the initial phase of his motion, then enters it during the medial phase, for being inside in the final phase. The link between J and P is here obviously a "partially overlaps" link, and, using the relations of Clarke[18], we write : PO(J,P) or also PO(P,J) since PO is a symmetrical relation.

In (18), John is inside the room during the initial phase of his motion, then goes out during the medial phase, for being outside in the final phase. Here again, the link between J

[16]One can object that any object can always be regarded as dynamic, if we choose for this an adequate referential. But the problem remains with now relative dynamicity of one object w.r.t one another.

[17]We normally have to use (cf. Sablayrolles 1991 ; 1992) stretch1 and stretch2 which denote the global duration of the motion described respectively in (17) and (18), and the function slice (x,y) which returns the spatio-temporal individual x which temporal length is restricted to the one denoted by y. We have then to talk about slice(J,stretch1) and slice(P,stretch1) for the motion described in (17) and about slice(J,stretch2) and slice(P,stretch2) for the motion described in (18). In order to lighten the notations used in this paper, we will in the following simply talk about J and P w.r.t. the motion described in (17) or in (18).

[18]We now consider under the name "relations of Clarke" the relations really defined by Clarke and the six one added by Randell & Cohn (cf. §3.4).

and P is a "partially overlaps" relation, and we write : PO(J,P) or also PO(P,J) always because of the symmetry of PO.

We can then see that we describe by the same relation two motions which have different semantics. We are not able to differenciate the direction of the motion of John w.r.t. the "static" entity (*"pièce"*).

3.5.2 A New Relation of Partial Temporal Order

Something more is necessary in the formalism of Clarke to differentiate the fact that John comes into or goes out of the room, something like a sort of precedence order. A precedence order between two spatio-temporal individuals w.r.t. a given motion could indeed allow to represent the relative direction of the motion of one of the entities. This order will of course be a partial order, because of its strong dependence on the motion we consider. It will in fact represent the "relative direction" of the motion in the space-time; it will reflect its proper temporality.

Clarke (1985) defined a basic temporal relation, the relation B, where B(x,y) means that "x is wholly before y". We cannot unfortunately define our precedence order from this temporal primitive because B is based on an unique linear time, common to all the individuals. Our precedence order is partial and based on the proper time of the considered motion.

We then propose to introduce a new relation of partial spatio-temporal order, the primitive[19] relation BST, where BST(x,y) means "x is spatio-temporally before y". We will here only present a discursive definition of this relation (cf. Sablayrolles 1991, for a complete formal definition).

> **BST(x,y)** <u>means</u> : there is a motion d such that d affects both spatio-temporal individuals x and y, and such that the direction (in the spatio-temporal meaning) of d goes from x to y.

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[19]It has been shown in (Sablayrolles 1991) that it is not necessary to consider BST as a primitve. It can be defined from syntactic functions (like *initial_loc(x)*, *verbal_category* ...) and from functions associated to our markers (as *LI(x)*, *ti* ..., for example).

We can explain and illustrate this definition using our two previous examples (17) and (18). In both cases, J and P are two spatio-temporal individuals affected by the motion of John.

For (17), we can, in an unformal way, say that J converges to P, ie. that the direction of the motion of John is towards the room. We then have, in the space-time, a direction of motion which goes from J to P. Our relation BST can then be applied with x standing for J and y for P. We obtain, for (17) : BST(J,P).

Now, in (18), J diverges from P, ie. the direction of the motion of John goes away from the room. In the space-time, we then have a direction of motion which goes from P to J. In this case, we can applied our relation BST if x stands for P and y for J. We then obtain, for (18) : BST (P,J).

We can thus have two different relations for describing our two different examples, namely, BST(J,P) for (17) and BST(P,J) for (18).

This is nevertheless not completely sufficient because we have lost the fact that a "partially overlaps" link stands between J and P. We propose to define a new relation, BPO, where BPO(x,y) means "x is spatio-temporally before and partially overlaps y" :

BPO (x,y) =def BST (x,y) ^ PO (x,y)

To close successfully our discussion about our two examples, we can say that, for (17), we have both BST(J,P) and PO(J,P), ie. BPO(J,P) and for (18), we have both BST(P,J) and PO(P,J), ie. BPO(P,J).

3.5.3 Generalization of the Solution

In the same way, we are able to redefine all the relations of Clarke for which this problem occurs, namely all symmetrical relations (more precisely, all symmetrical non reflexive relations, as we will see later on). However, it seems not useful to redefine all these relations, because of the lattice structure.

Six of the relations of Clarke can be adopted as basic, mutually exclusive, relations for our work. Namely, DC ("disconnected from"), EC ("externally connected to"), = ("identical with"), PO ("partially overlaps"), NTPP ("nontangential proper part") and TPP ("tangential proper part").

The relations DC and EC are symmetrical and present the same problem as PO. We consequently redefine them as :

BDC (x,y) =def BST (x,y) ^ DC (x,y)

"x is spatio-temporally before and disconnected from y"

BEC (x,y) =def BST (x,y) ^ EC (x,y)

"x is spatio-temporally before and externally connected to y"

The identical relation is symmetrical, but also reflexive. The problem previously evoked does not occur because one individual cannot have a motion relative to himself.

We have already dealt with the relation PO, that we have redefined as BPO.

The relation NTPP is asymmetrical and consequently raises no problem.

At least, the relation TPP is perhaps the most complex.

3.5.4 A Second Problem

Let us take another exemple, with the sentences (19) and (20), which occur in a context where Mary was swimming in a lake.

(19)*Marie a nagé jusqu´à la rive*

Mary has swum until the bank

(20)*Mary s´est éloignée de la rive (en nageant)*

Mary has swum away from the bank

Let us use the letters M and L to denote the temporal restriction of the spatio-temporal individual corresponding respectively to Mary and to the lake, restriction to the global temporal length of the motion considered.

In both motions Mary is swimming in the lake and is connected to the bank (at the end of her motion in (19); at the beginning of it in (20)). To describe the link between M and L, we can, for both motions, use the relation "tangential proper part" and write : TPP(M,L).

Unfortunately, we cannot use the same solution as for PO, because TPP is not a symmetrical relation. We can nevertheless try to use our new relation BST. What have we ?

In (19), Mary is swimming away from the center of the lake, till the bank. Here, we have a kind of "internal divergence" of M w.r.t L, ie. a direction of motion, in the space-time, which goes from L to M. The relation BST(L,M) then holds in this case.

In (20), Mary is swimming "towards" the center of the lake, at least away from the bank. In this case, we have a kind of "internal convergence" of M w.r.t L, ie. a direction of motion, in the space-time, which goes from M to L. It is the relation BST(M,L) which holds here.

To sum up, in (19), we have TPP(M,L) and BST(L,M); in (20), we have TPP(M,L) and BST(M,L). If we try to use the same solution as for the relation PO, we define the new relation BTPP as :

BTPP (x,y) =def BST (x,y) ^ TPP (x,y)
"x is spatio-temporally before and a tangential proper part of y"

This new relation can be used for (20), with x standing for M and y for L. But we have nothing to deal with the case (19) ! That means that for the relation TPP, it is not the redefinition as one new relation (BTPP), but a division in two new relations that we must realize. We propose the two following relations :

BTPP (x,y) =def BST (x,y) ^ TPP (x,y)
"x is spatio-temporally before and a tangential proper part of y"

BiTPP (x,y) =def BST (y,x) ^ TPP (x,y)
"y is spatio-temporally before x and x is a tangential proper part of y"

To close successfully our example, we can write, for (19), BiTPP(M,L), and for (20) BTPP(M,L).

3.5.5 The Final Set of New Spatio-Temporal Relations

We finally obtain a set of thirteen new spatio-temporal relations, namely BDC, BEC, =, BPO, NTPP, BTPP and BiTPP, and their respective reciprocal relations, noted BDCi, BECi, =, BPOi, NTPPi, BTPPi and BiTPPi, (see right part of figure 11 for a graphical illustration of these relations), which allows us to describe all the possible links between two spatio-temporal individuals in the framework of motion.

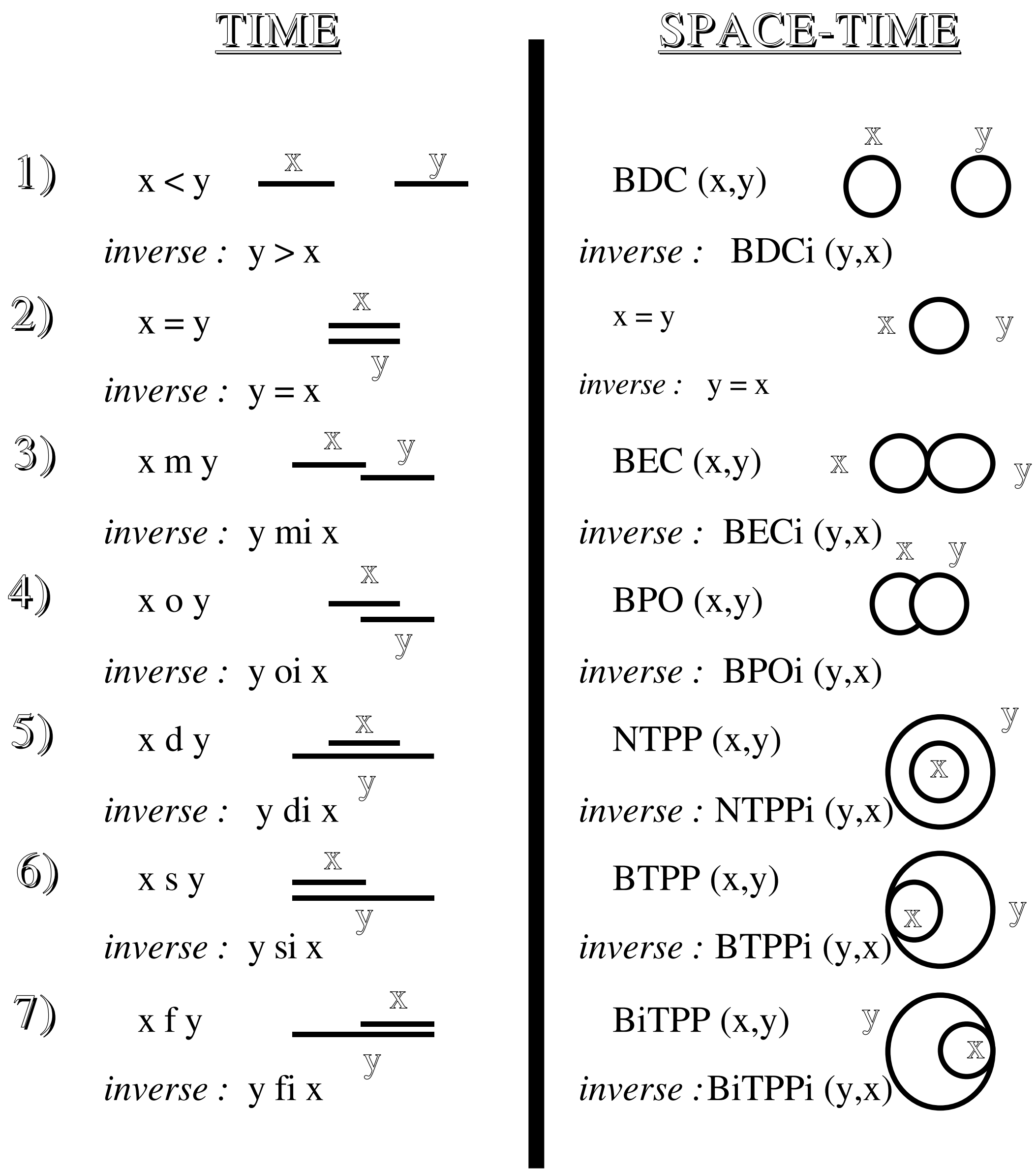


Figure 11 : parallelism between Allen´s relations and our new relations

3.5.6 Conclusion

In figure 11, we have shown a parallelism between the temporal relations of Allen (which are applied between 1-dimensional temporal entities, the intervals), and our set of new spatio-temporal relations (which are applied between 4-dimensional spatio-temporal individuals). With the help of this graphical illustration, we can easily observe that these two sets of relations present strong similarities.

This is the result of the fact that, from a formal point of view, we conceptualize 4-dimensional spatio-temporal individuals as simple 1-dimensional entities, but without loosing any of their spatial and temporal properties, since this 1-dimensionality in fact corresponds to the axis[20] in the space-time which supports the direction of the motion of this individual[21].

3.6. Formal Representation of the Spatio-Temporal Semantics of Expressions of Motion

3.6.1 Introduction

In this paragraph, we introduce the representational rules that are used to build the two levels of the semantics of expressions of motion. The choice of the right rule to use is dependent on the values of the three criteria of the type of motion and on the aspectual polarity of the verb involved in the expression of motion.

Instead of just giving tables of rules, we would like to illustrate and comment on some of them through an example. In §3.7 we will have the occasion to treat completely (linguistic and representational levels) an expression of motion. In order to make something different and also to show more concretely the difference between the two levels of the semantics, we have chosen not to treat an expression of motion, but a type of motion, namely : motion (I,1,int).

3.6.2 The Representational Rules Presented Through an Example

3.6.2.1 The Example : the Type of Motion : motion(I,1,int)

If we come back to the compositional rules expressed in §2.4, we can try to find which compositions can produce the type of motion : motion (I,1,int).

The rule 1-a can unfortunately not be used because it produces only types of motion with medial or final polarity.

The rule 1-b also produces only types of motion with final polarity.

The rule 2 can be used with the following constraints (we have used the question mark to indicate unconstrained values) :

---

[20]Here, "axis" has not to be understood as a whole straight line, but as a curve, in the space-time, following (in space and in time) the motion of the moving entity.

[21]In the case of static individuals, this "axis" in fact is identical with the time axis.

Vdp (?,1,?) + L_Prep (I,int) => motion (I,1,int)

We have two unconstrained values for the verb, namely the value of the polarity criterion (which can be "I" for initial, "M" for medial or "F" for final), and the value of the criterion of the relation of localization (which can be "int" for internal" or "ext" for external). Let us consider the six possible combinations of these values :

(i)	Vdp (I,1,int)	: possible
(ii)	Vdp (F,1,int)	: possible
(iii)	Vdp (M,1,int)	: not accepted in French[22]
(iv)	Vdp (I,1,ext)	: empty class of verbs
(v)	Vdp (F,1,ext)	: empty class of verbs
(vi)	Vdp (M,1,ext)	: empty class of verbs

In order to illustrate this combinations with expressions of motion, let us arbitrarily choose in the group of the preposition and in each possible group of verb one particular element.

For the preposition, we have the group L_Prep(I,int) : we choose, for example, the preposition *"de"* (from).

For the verb, in the case (i), we have the group Vdp (I,1,int) : we choose the verb *"partir"* (to leave); in the case (ii), we have the group Vdp (F,1,int) : we choose the verb *"arriver"* (to arrive).

We can illustrate the cases (i) and (ii) by (21) and (22), respectively.

(21)*Jean est parti du jardin*

John has leaved the garden

(22)*Jean est arrivé du jardin*

John has arrived from the garden

---

[22]Vdp (M,1,int) + L_Prep (I,int) corresponds, for example, at the following expression of motion : *"Jean passe (par) du jardin"* (John goes over from the garden"), which is linguistically not accepted in French.

3.6.2.2 The First Level Semantics Relations

3.6.2.2.1 Definitions

We firstly represent the first level semantics. This level, or imprecise level, describes the relations between the moving entity and, respectively, the Ns and the LRV. We then need two relations for this : the first between the moving entity and the Ns; the second between the moving entity and the LRV.

We give in figure 12 the rules to obtain these relations.

The first relation is dependent on the value of the polarity criterion (I, M or F) and of the criterion of the relation of localization (int or ext) of the type of motion.

The second relation is dependent on the value of the criterion of change or non change of space of reference (1 or 2) of the type of motion and of the value of the polarity criterion (I, M or F) of the verb involved.

criteria 1 and 3 :

Iint :	BiTPP (slice (cible, ti), LI)[23]
Iext:	BDCi (slice (cible, ti), RLI)
Mint :	[BiTPP (slice (cible, tm), LM) ^ BTPP (slice (cible, tm), LM)] v NTPP (slice (cible, tm), LM)
Mext :	[BDC (slice (cible, tm), RLM) ^ BDCi (slice (cible, tm), RLM)] v [BDC (slice (cible, tm), RLM) ^ BECi (slice (cible, tm), RLM)] v [BEC (slice (cible, tm), RLM) ^ BDCi (slice (cible, tm), RLM)] v [BEC (slice (cible, tm), RLM) ^ BECi (slice (cible, tm), RLM)]
Fint :	BTPP (slice (cible, tf), LF)
Fext :	BDC (slice (cible, tf), RLF)

[23]"slice (x,y)" is a function which returns the spatio-temporal individual x which temporal length has been restricted to the one denoted by y;
"cible" has to be matched with the moving entity. Here, in our example, with *"Jean"*.

criterion 2 + category (I/M/F) of the verb :

1 + verb I : BiTPP (slice (cible, ti), LI)
1 + verb M : BiTPP (slice (cible, tm), LM) ^ BTPP (slice (cible, tm), LM)
1 + verb F : BTPP (slice (cible, tf), LF)
2 + verb I : BDCi (slice (cible, ti), RLI)
2 + verb M : [BDC (slice (cible, tm), RLM) ^ BDCi (slice (cible, tm), RLM]
v NTPP (slice (cible, tm), LM)
2 + verb F : BDC (slice (cible, tf), RLF)

Figure 12 : first level semantics relations

3.6.2.2.2 Use in Our Example

If we come back to our illustration, for both case (i) and (ii), we have the type of motion : motion (I,1,int). The values "I" and "int" lead to the choice of the following first relation :

for (i) & (ii) : BiTPP (slice (cible, ti), LI) where LI stands for Ns

For the selection of the second relation, we have the value "1" for the criterion of change or non change of space of reference of the type of motion. For the polarity of the verb, we have two different values : for (i), we have the value "I"; for (ii), the value "F". We then obtain two different second relations :

for (i) : BiTPP (slice (cible, ti), LI) where LI stands for LRV
for (ii) : BTPP (slice (cible, tf), LF) where LF stands for LRV

3.6.2.3 The Second Level Semantics Relations

3.6.2.3.1 Definitions

We then look at the second level semantics, or precise level. At this level, we make the first level fully precise by adding the relation which stands between the LRV and the Ns. This relation is needed, as we can see in our example.

In (i), we have obtained two identical relations, but in the first, the marker LI stands for Ns, and in the second for LRV. With only this information, we can just say that the place represented by the Ns is inside, equal or contains the place represented by the LRV.

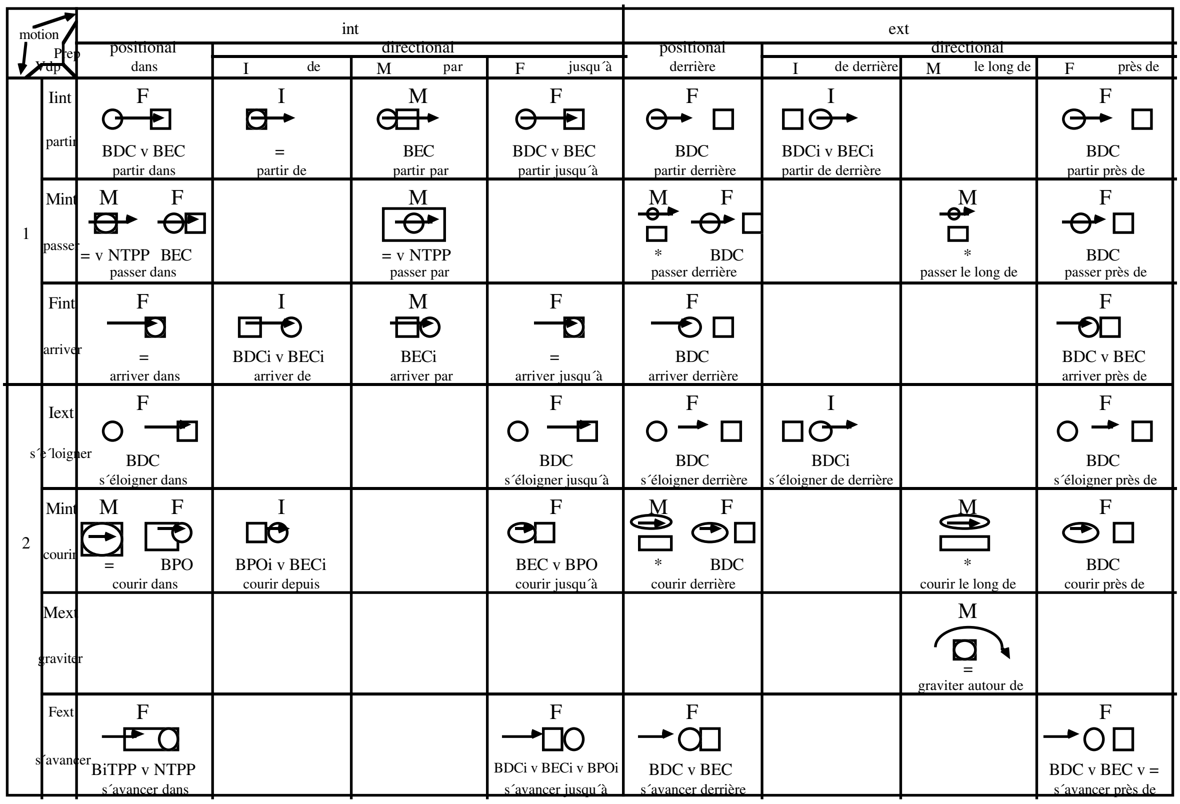
In (ii), the two relations obtained give no information about the possible links between the LRV and the Ns.

We propose the following table (cf. fig 13) which represents in its columns the eight groups of spatial prepositions and the criterion of the relation of localization for the resulting type of motion (the value of this criterion is always given by the preposition). In its rows the seven groups of motion verbs and the criterion of change or non change of space of reference of the resulting type of motion are represented (the value of this criterion is always given by the verb).

This table has to be read as follows : one box represents an expression of motion which is obtained by the combination of a motion verb which group corresponds to the row of this box and a spatial preposition which group corresponds to the column. This expression of motion describes a motion which belongs to the type of motion which criterion of polarity is written at the top of the box (I, M or F), which criterion of change or non change of space of reference is given by the row and which criterion of relation of localization is given by the column.

In each box, a graphical illustration, with a circle standing for the LRV, a square standing for the Ns and an arrow standing for the motion of the moving entity, is proposed. An example in natural language is also given. At least, the relation (or a disjonction of relations) standing between LRV and Ns is precised.

Empty boxes correspond to non linguistically acceptable combinations (in the French language).



* : {BDC ^ BDCi} v {BEC ^ BECi}

Figure 13 : second level semantics relations

3.6.2.3.2 Use in Our Example

To achieve our example, (i) corresponds to the box situated at column 2, row 1, and (ii) at column 2, row 3. We then obtain the following relations :

for (i) : LRV = Ns

for (ii) : BDCi (LRV, Ns) v BECi (LRV, Ns)

3.7. Some Possibilities of Natural Spatio-Temporal Reasoning

3.7.1 A Simple Example

We propose to show, as an example of the possibilities of reasoning with our representations, the inference which consists of condensing the following text (23) (which expresses two successive motions) into one sentence (which expresses just one global motion).

(23)*Jean est passé du jardin dans la maison par la terrace. Puis Jean est sorti de la maison dans la rue.*

John went from the garden into the house by the terrace. Then John went out of the house into the street.

3.7.2 Analysis of the First Sentence

Let us detail the analyse of the first sentence. We have the verb *"passer"* which belongs to the group : Vdp (M,1,int) and three prepositions : *"du"* (which is a contraction of *"de le"* and belongs to L_Prep (I,int)), *"dans"* (which belongs to L_Prep (int)) and *"par"* (which belongs to L_Prep (M,int)). We applied the compositional rules (cf. §2.4) for the combination of the verb with each preposition :

"passer du"	: Vdp (M,1,int) + L_Prep (I,int) => motion (I,1,int)	(a)
"passer dans"	: Vdp (M,1,int) + L_Prep (int) => motion (F,1,int)	(b)
"passer par"	: Vdp (M,1,int) + L_Prep (M,int) => motion (M,1,int)	(c)

We then select the two adequate relations of the first level semantics corresponding to the values of the criteria of each type of motion, using the representational rules (cf. §3.6) :

(a) BiTPP (slice (cible1, ti1), LI1=*"jardin"*)
BiTPP (slice(cible1, tm1),LM1=*"terrasse"*) ^ BTPP (slice(cible1,tm1),LM1=*"terrasse"*)

(b) BTPP (slice (cible1, tf1), LF1=*"maison"*)
BiTPP (slice(cible1,tm1),LM1=*"terrasse"*) ^ BTPP (slice(cible1,tm1),LM1=*"terrasse"*)

(c) {BiTPP (slice(cible1,tm1),LM1=*"terrasse"*) ^ BTPP(slice(cible1,tm1),LM1=*"terrasse"*)}
v NTPP (slice (cible1, tm1), LM1=*"terrace"*)
BiTPP (slice(cible1,tm1),LM1=*"terrasse"*) ^ BTPP (slice(cible1,tm1),LM1=*"terrasse"*)

In (c), we obtain for the first relation a disjunction of relations. This is due to the double interpretation for medial and internal verbs that we have already mentioned in §2.4. This disjunction (exclusive disjunction) is here easily solved by means of the second relation, which is equal to the first part of the disjunction. This verb and its three prepositions in fact describe a same motion; we then group (a), (b) and (c) as a conjunction of relations. We obtain :

(d) BiTPP (slice (cible1, ti1), LI1=*"jardin"*)
BiTPP (slice(cible1,tm1),LM1=*"terrasse"*) ^ BTPP (slice(cible1,tm1),LM1=*"terrasse"*)
BTPP (slice (cible1, tf1), LF1=*"maison"*)

3.7.3 Analysis of the Second Sentence

For the second motion (second sentence), we proceed analogously and obtain :

"sortir de"	BiTPP (slice (cible2, ti2), LI2=*"maison"*) BiTPP (slice (cible2, ti2), LI2=*"maison"*)	(e)
"sortir dans"	BTPP (slice (cible2, tf2), LF2=*"rue"*) BiTPP (slice (cible2, ti2), LI2=*"maison"*)	(f)

We then consider the conjunction of (e) and (g) :

(g) BiTPP (slice (cible2, ti2), LI2=*"maison"*)
BTPP (slice (cible2, tf2), LF2=*"rue"*)

3.7.4 The Primordial Utility of the Global Duration

With the only knowledge of this little text, and with the presence of the adverb *"puis"*, we suppose these two motions are successive motions without any other in between. Here, there is an overlap of the global durations[24] of these two motions which is such that (from its definition) tf1=ti2, ie. the final phase of the first motion temporally coincides with the initial phase of the second. This insures the spatio-temporal continuity of *"Jean"* and *"maison"*, which allows us to write down the equalities : cible1=cible2 and LF1=LI2. If we apply this to the obtained representations (d) and (g), we have :

(h) BiTPP (slice (cible1, ti1), LI1=*"jardin"*)
BiTPP (slice(cible1,tm1),LM1=*"terrasse"*) ^ BTPP (slice(cible1,tm1),LM1=*"terrasse"*)
BTPP (slice (cible1=cible2, tf1=ti2), LF1=LI2=*"maison"*)
BiTPP (slice (cible2=cible1, ti2=tf1), LI2=LF1=*"maison"*)
BTPP (slice (cible2, tf2), LF2=*"rue"*)

3.7.5 The Result of the Inference

Let us just introduce the number 3 to denote the infered representation, and lay down the following affectations : cible3=cible1=cible2; LI3=LI1; LM3=LM1+LF1; LF3=LF2. Applying this in (h), we finally obtain (i) :

(i) BiTPP (slice (cible3, ti3), LI3=*"jardin"*)
BTPP (slice (cible3, tf3), LF3=*"rue"*)
{BiTPP (slice (cible3, tm3), LM3=*"terrasse et maison"*) ^
BTPP (slice(cible3,tm3),LM3=*"terrasse et maison"*) }

Here, we recognize the description of a motion expressed in natural language by a verb Vdp (M,1,int), and three prepositions : one, L_Prep (I,int) associated to the place *"jardin"*; one, L_Prep (int) associated to the union of places *"terrasse et jardin"*; and one, L_Prep (M,int) associated to *"rue"*.

3.7.6 Presentation of the Result Under a Natural Language Form

In order to present this result under a natural language form, let us make an arbitrary choice of one precise verb and three precise prepositions in the groups we have just found. We can then describe the result of our spatio-temporal reasoning by, for example, the following sentence :

---

[24]Here, we can remark that with the concept of normal duration, we would only have that the normal duration of the first motion precedes or meets (to use Allen´s terminology) the normal duration of the second.

(24)*Jean est passé du jardin dans la rue par la terrasse et la maison.*
John went from the garden into the street by the terrace and the house.

3.7.7 Conclusion

This result is plainly in accordance with what human beings would infer about our little text (23). However, this is just an example of spatio-temporal reasoning that can be realized on our representations. We would like to study soon this inferential level more deeply.

4. CONCLUSION

The work we have presented constitutes the pursuit of complementary collaborations of linguistic and formal studies of the semantics of natural language, started some years ago in the "Groupe Langue, Raisonnement, Calcul", at the IRIT, University of Toulouse, France. This interdisciplinary approach, in the case of the study of expressions of motion, is however only at its beginning. We proposed some interesting extensions that we would like to investigate. Firstly, the integration of agents and intentionality seems to be promising. One more important extensions concerns the spatio-temporal reasoning level. Two different frameworks seem interesting for our study. In the case of motion, a crucial problem is the determination of the temporal validity of our spatio-temporal relations. The "event calculus" (Kowalski and Sergot 1986) satisfies two basic constraints of this problem : the underlying default logic of the model is well adapted to the non-monotonicity of the deductions; and the temporal structures of the "event calculus" are closely associated to non-temporal knowledge. This part of the research is developped by Borillo M. and Gaume (1990) for the spatio-temporal reasoning and by Bernard, Borillo M. and Gaume (1991) for the temporal study of the intentional transformations (planning) of the physical world. The study of semantics of motion naturally comes within a cognitive perspective, where the linguistic analysis and the logical models of reasoning will have to be associated within the interpretation of discourse. The second is the DRT (Discourse Representation Theory) developed by Kamp (1979). We have seen in §3.7 that spatio-temporal reasoning also requires the possibility to deal with discourse. Bras (1990) has developed inside the DRT framework a calculus of the temporal structures of a French discourse. Recent works on DRT have also shown the necessity of the introduction of inferential mechanisms, triggered by some linguistic forms, to interpret discourse (Asher and Lascarides 1991). At the DFKI, University of Saarbrücken, Germany, a high-performance temporal reasoner on DRT representations (DRS) has been built and implemented by Kasper. We would like to study how these different components can all be associated and work together in the DRT framework. The last important extension concerns the formalism of Clarke. We would like to associate the modifications we have made to this formalism to topological and functional extensions already made by Vieu (1991) and Aurnague (1991). These modifications are also closed to natural language preoccupations. An implementation of this whole system is planned in the framework of the project VILAIN (VIsion and LAnguage INtegration) developped in the group of Toulouse (Aurnague, Borillo M., Sablayrolles). It deals with construction and description of graphical scenes using natural language (spatial places and motions).

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