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Spatial entities are temporal entities too: the case of motion verbs

Nicholas Asher, Philippe Muller, and Mauro Gaio

Abstract

We argue that spatio-temporal primitives are crucial in giving a full view of the spatial and temporal structure of texts. We think that temporal and spatial structure are projections of a more complex and more complete spatio-temporal structure. We will make our case based on the an analysis of movement verbs, showing how they contribute in an important way to both temporal and spatial structure within discourse. Our analysis of movement verbs is based on a detailed lexical semantic analysis of a wide class of verbs in French. We give some ideas for how this lexical semantics when coupled with an analysis of how clauses involving these expressions are related to each other within a discourse using rhetorical relations can aid in determining the spatio-temporal structure of the text. We apply our approach to descriptions of climbing cliffs as well as descriptions of walking tours in the Pyrenees and descriptions of itineraries in Toulouse. We think that this provides sufficient justification for including movement verbs and spatio-temporal information in general within the specification of a SpatialML or rather its fusion with TimeML.

1 Introduction

Many texts are full of spatial information, descriptions of itineraries, trajectories and locations. This spatial information is, however, very often bound together with temporal information, in particular through the descriptions of movement both at the lexical, clausal and discourse levels. The fact that this is so is made particularly clear in certain texts, which include descriptions of itineraries. We argue that spatio-temporal primitives are crucial in giving a full view of the spatial and temporal structure of texts. We think that temporal and spatial structure are projections of a more complex and more complete spatio-temporal structure. We will make our case based on the

an analysis of movement verbs, showing how they contribute in an important way to both temporal and spatial structure within discourse. We think that this provides sufficient justification for including movement verbs and spatio-temporal information in general within the specification of a SpatialML or rather its fusion with TimeML (Pustejovsky et al., 2005).

Our analysis of movement verbs is based on a detailed lexical semantic analysis of a wide class of verbs in French. We give some ideas for how this lexical semantics when coupled with an analysis of how clauses involving these expressions are related to each other within a discourse using rhetorical relations can aid in determining the spatio-temporal structure of the text. We have assembled a small corpus involving descriptions of climbing cliffs as well as descriptions of walking tours in the Pyrenees and descriptions of itineraries in Toulouse (Privot, 2004), from which we will draw certain illustrative examples to support our thesis.

One of our principal aims is to add to the annotations proposed for space parameters or primitive s relevant to encoding motion. In SpatialML¹, the spatial information that is encoded is almost all static, except for the PATH elements.

The vast majority of motion verbs, for instance, indicate a spatial trajectory through time: if we want to know for instance the position of an object at a certain time given the information within a particular text, we often have to know what motions it has undergone. Consider the following example

- (1) Laisser la voiture au parking de Sinsat et prendre le sentier du rocher école. Continuer après le secteur "de la dalle", vers le secteur "du lac" qui surplombe l'Ariege. (*Escalade en Haute Ariege*,

¹SpatialML: Annotation Scheme for Marking Spatial Expressions in Natural Language, March 30, 2007, Version 1.0, <http://kent.dl.sourceforge.net/sourceforge/spatialml/SpatialML-1.0-March30-2007.pdf>

Thierry et Colette Pouxviel, Publications Sicre, 1993)

This text involves a sequence of "instructions" of how to get to different sectors of a climbing cliff. *Laisser* is a verb that implies a leaving of the parking lot, while *prendre* is a verb that tells us the direction of the itinerary from the parking lot. It does so by locating the movement along or within another location, a path, *le sentier du rocher école*. The instructions following are sequenced together to give a narrative of how one proceeds through time and space to various sections of the cliff. This is a typical description of an itinerary and one couldn't begin to separate out purely spatial information from the temporal information. For instance, there are no directions given, no distances given. There is a path that one follows. But that is all that is needed to figure out the geographical site of the climbs. This is just one instance of why we think that an annotation scheme for texts and a conception of spatial information within a text should not separate spatial from temporal information. In particular, temporal information can often organize spatial information, as for instance in a description of a walk-through of an apartment, or of an itinerary to a climbing spot.

2 Previous work

In previous work, we have worked on the spatiotemporal information encoded in verbs (Asher and Sablayrolles, 1995; Muller and Sarda, 1997), as well as on how discourse structure conveys spatio-temporal information through the use of discourse relations (Asher et al., 1995; Prvot, 2004). We have based our work on formal investigations of topological information encoded in prepositions (Vieu, 1991) and verbs (Muller, 2002), for which we were able to provide a complete axiomatization (Asher and Vieu, 1995). Geometrical information was a lot harder to axiomatize; most extant attempts in the AI field to provide axiomatizations of geometrical information fail to preclude completely unintuitive interpretations within the natural numbers (see the thesis of (Donnelly, 2001) for some telling examples of how badly various proposed axiomatizations have fared in capturing the intended model R^3).

An assumption underlying this work was that lexical semantics as well as discourse information provided spatio-temporal information and needed to be integrated to provide a correct analysis of spatio-temporal structure in text (Asher et al., 1995). Recently, we have begun to annotate corpora for discourse structure in a large scale effort to examine empirically the effects of discourse structure in a variety of domains (anaphora resolution, temporal structure of texts, evaluating opinions in texts, *inter alia*). We can add spatio temporal structure to that list of effects that we would like to study. We

think that these texts amply support the idea of encoding spatio temporal information, in particular the information encoded in movement verbs, in any attempt to get at the spatial information expressed in the text.²

3 Our corpus

Our corpus includes climbing guide texts, texts on ski randonnée outings and mountain biking guide books to various areas in the Pyrénées. We also have access to a number of descriptions by famous and not so famous authors of their journeys through the Pyrenees from the Mediathèque in Pau used in GIS project described in (Lousteau et al., 2008). The climbing guides have short to medium descriptions of situations of cliffs and the climbs or boulder problems on them. They contain some straightforward geographical information and well-known towns or location. They are also usually well laid out with subsections that give rise to discourse structure that can be easily captured in automatic fashion. In this structure each subsection elaborates on its parent. Each subsection includes graphics or text and usually important spatial information. For example, a typical climbing guide presents a site Arabaux by first giving its geographical location and then goes on to describe the various sectors of the cliffs. It begins in the following way:

- (2) A 3km au nord-est de Foix, le petit village d'Arabaux est dominé par plusieurs barres calcaires juxtaposées. Celles-ci proposent dans leurs parties centrales un fabuleux potentiel de blocs. Dans les années 70 et 80, plus de 150 passages existaient. Il s'agissait souvent de blocs hauts pratiqués en moulinette. Les plus beaux ont ensuite été équipés... (Jean Denis Achard *Escalades en Ariège: Le Plantaurel*, Lavelanet: Noisetier, 2000)

It is not completely straightforward to isolate the spatial information. Here the first sentence uses a frame adverbial to situate the village of Arabaux, which is dominated by "several limestone cliffs". An anaphor then links the cliffs "in their central parts" to the "fabulous potential of boulder problems" which the text then goes on to give a historical background to.

The next section gives directions to the site and the section 'Acces aux voies' directions to the different areas of the site. These directions resemble those in (1) and use movement verbs to provide information relevant to the spatial location of objects. The sections on each site give physical details of the different routes or problems in the site. Some guidebooks give comments on the difficulty or the type of climb, and some give important information

²This conclusion is also supported by the work in (Lousteau et al., 2008).

about how to climb or do the particular problem which may important spatial information (start to the left of the big boulder).

The description of itineraries using motion verbs and temporal adverbials having a spatio-temporal usage is common not only in the climbing guides but in the ski guides and others. Here is an extended example describing a complete itinerary to the top of a mountain, the Mont Rouch, a difficult ski tour in the Pyrenees.

- (3) Suivre le sentier balisé (jaune) qui remonte la vallée de Leziou rive gauche dans la forêt. Après une montée raide, on débouche sur le plateau de Leziou (1662m) direction sud. On peut remarquer sur la gauche une cabane de berger; continuer sud jusqu'à l'altitude de 1930m puis obliquer en direction des Clos de Dessus. Plateau idéal pour bivouaquer ou dormir à la nouvelle cabane 4 places située en contrebas du plateau. Continuer à se diriger plein est sur la rive droite du ruisseau, laisser les skis et gagner la crête orientée sud pour attendre l'arête frontalière qui mène au sommet. (Daniel Daubin, Michel Dedieu, *Cent Randonnées à Ski en Ariège, Andorre, Pyrénées Orientales*, Randonnées Pyrénéennes, 1992)

Other texts in our corpus are narratives of journeys taken through the Pyrenees. Much less structured, they nevertheless exhibit some of the same tendencies. They do not have a wealth of precise spatial information and often use temporal information to situate the journey. About 30% of the temporal adverbs in those texts have a spatio-temporal use of the sort explored in (Vieu et al. 2005).

4 A word on semantic types

Prior to our semantics, we need to think a bit about ontology. Like SpatialML we think it important to make a distinction between places or locations (fixed elements in the terrestrial reference frame) and objects (elements that have a complex internal structure and typically move with respect to the terrestrial reference frame). (Asher, 2007) argues that a failure to keep the types of object and place distinct will lead to difficulties in formulating relations of inclusion for spatial prepositions like *dans* (Vieu, 1991). It also appears that a failure to distinguish between objects and places will miss grammaticalizations of these categories. For instance, in Basque there are two genitive cases *-ko* and *-ren* and they have a quite interesting distribution, once one distinguishes between geographical locations and objects; locations in general easily take the genitive *-ko* but not *-ren*, whereas objects in general do the reverse (Aurnague, 2004).

(Asher, 2007) proposes a possible test for the distinction between an object and a location using the alternation

in English *in* or *at* versus *inside*. One can easily say that one is at or in a location. One can also be *in* or *inside* a physical object. On the other hand, it is dispreferred to say that something is inside a location but quite alright to say that it is inside an object, if it's enclosed. Similarly, the relative pronoun *where* refers to locations rather than physical objects.

- (4) a. *The worm is inside /in the apple. ??The apple is where the worm is.*
 b. *John is in/?inside New York. New York is where John is.*
 c. *The tractor is in/??inside the field. The field is where the tractor is.*

Given the conceptual and grammatical reasons for making the distinction between places and object, it's very surprising to note, as (Aurnague, 2004) does, that some lexical items appear to act both like objects and like places. Aurnague calls these "mixed entities". Mixed entities are things like buildings; they have a complex internal structure like other movable objects but which are also fixed elements with respect to the terrestrial reference frame. Thus (Aurnague, 2004) distinguishes the following:

- places: *valley, field, river, mountain, hill ...*
- objects: *apple, glass, chair, car ...*
- "mixed entities": *house, church, town hall ...*

Using the grammatical clues given in Basque, Aurnague suggests that a mixed entity noun (as *castle* in the example below) functions both as an object and a place.

- (5) *Gazteluko paretak harriz eginak dira, haren dorre zaharra aldiz egur eta buztinez.* ('The walls of the castle are made of stone, its old tower however (is made) of wood and clay')

If we attend to the distribution of *in* and *inside* in English with objects that have an inside and use that as a key to distinguishing between the way their objects are typed, then it appears that houses, as well as trains and kitchen drawers can be understood not only as physical objects but as locations as well. Cities can be understood as locations but also as many other things—political organizations and even physical objects as well

- (6) a. *The checkbook is inside the drawer. The drawer is where the checkbook is.*
 b. *I'm inside a train where there are some very comfortable seats.*
 c. *John must be inside the house where there are some very expensive paintings.*
 d. *There are some beautiful paintings inside the house where John resides.*

A careful study of ontological categories relative to the spatial domain reveals both a distinction between locations, objects and mixed entities and various means for shifting from one type to the other. More important, for our purposes, is to single out among spatiotemporal entities the usual temporal entities (eventualities, dates and times) and to also signal that many eventualities typically have a spatial as well as a temporal dimension. We will focus on a particular subtype of eventuality conveying important spatiotemporal information, movement eventualities, in the next section

5 Movements and the verbs that express them

Our lexical semantics taken from (Asher and Sablayrolles, 1995) and (Muller and Sarda, 1997) comprises an exhaustive list of transitive and intransitive motion verbs in French (about 400 in all), which we classify into:

- change of location verbs which are arranged into 10 general types according to the type of motion involved.
- change of position verbs (within a given location) (e.g., *circuler*, *parcourir*, *sillonner* (*circulate*))
- inertial change of position verbs (within a given location) (e.g., *courir*, *danser*, (*run*, *dance*) etc.³
- change of posture verbs (*s'asseoir*, *se lever* (*sit down*, *stand up*)).

Some distance information is also encoded to describe the motion. In addition to the temporal prepositions that can also have a spatiotemporal use, we draw on the classification 189 prepositions in French having an almost exclusive spatial use organized into 16 general types. With each general type we associate a particular feature structure that specifies the verb in terms of its "polarity," the relation it evokes within the background mereotopological framework developed by (Vieu, 1991) and extended to space-time by (Muller, 2002), and whether or not it is a telic verb. Here for instance is an example of a transitive verb from the initial, telic internal verb class:

quitter									
Event_Str	<table border="1"> <tr> <td>event</td> <td></td> </tr> <tr> <td>target:</td> <td>27</td> </tr> <tr> <td>landmark:</td> <td>28</td> </tr> <tr> <td>process:</td> <td>quitter'</td> </tr> </table>	event		target:	27	landmark:	28	process:	quitter'
event									
target:	27								
landmark:	28								
process:	quitter'								
Mvt_Str	<table border="1"> <tr> <td>polarity</td> <td>initial</td> </tr> <tr> <td>loc. rel.:</td> <td>internal</td> </tr> <tr> <td>telicity</td> <td>true</td> </tr> </table>	polarity	initial	loc. rel.:	internal	telicity	true		
polarity	initial								
loc. rel.:	internal								
telicity	true								

³It should be noted as we have done in previous work that these verbs in French behave quite differently from the way manner of motion verbs in English are described, e.g., by Beth Levin.

Transitive movement verbs in general make their subjects be the target. Initial transitive verbs specify the landmark as the *source* via their direct objects or internal arguments, while final transitive verbs specify the landmark as the *goal* or end location of the movement via their direct objects. The internal argument of a median verb specifies a path argument, a location at which the target is located throughout the movement. The feature *internal* describes a relation between the target and source or initial point of the movement that holds at the beginning of the displacement and no longer holds at the end of the event. Besides the internal relation, Muller and Sarda as well as Sablayrolles and Asher and Sablayrolles provide other relations describing topological relations between the target and the landmark; these topological relations are the basis of the taxonomy of transitive verbs made by Muller and Sarda. Besides these topological relations, Sablayrolles appeals to zones which incorporate some crude distance information into the lexical semantics of movement verbs. For example, according to Sablayrolles, the French verbs *arriver* and *entrer* are both final, telic, internal verbs, but *entrer* suggests that the displacement originates from somewhere not inside but close to the goal location, whereas *arriver* does not have this meaning. We would represent this information within particular spatio-temporal relations that incorporate geometrical as well as topological information.

Like SpatialML we want to include as features the other PATH attributes: Direction, Distance and Frame. These can also contribute to the specification of a verb class. Verbs like *obliquer* (*proceed at an angle from one's present direction*) would specify a value for the Direction attribute.

Coercions or cocompositions in the sense of (Pustejovsky, 1995) may turn certain verbs into movement verbs—for instance, when a location is given as their internal argument or external argument. For instance, the verb *suivre* (*follow*) when it takes a location or a sign to some location is clearly a movement verb. *Mener* (*lead*) is a movement verb when its subject is a location (a path).

6 How we would go about acquiring spatio-temporal information automatically or semi-automatically

Our detailed lexical semantics is nice and we think that we need these features in any adequate coding of spatiotemporal information. From the standpoint of automatic construction of these feature structures, however, we think that we need to pay attention to how discourse structure interacts with lexical semantics. Below, we will sketch an approach to text annotation in which lexical information, compositional semantics as well as discourse provide information crucial to the automatic annotation

of spatial temporal information. With a good syntactic parser, we can capture relatively reliably argument structure of motion verbs, as well as sentential spatial IP adverbs or frame adverbials which have been argued to be important discourse devices and which (Vieu et al., 2005) have shown how to integrate within a framework of formal discourse interpretation. We hope to use such a syntactic parse together with manual annotations to arrive at a corpus from which we can induce a discourse parser. Having tried already on open domain texts (DISCOR, NSF project IIS-0535154), we know that the problem of induction rears its head for us in the form of sparse data: we need to annotate a lot of texts to have a decent discourse parser. One hope we have is to use more symbolic means to compute discourse structures. This seems to be not feasible for the moment in open domain texts with a general discourse structure annotation scheme. But by restricting our attention to a certain type information like spatio-temporal information, we hope to be able to have a more tractable task.

Rhetorical structure is an important element in understanding the spatio temporal information conveyed by a text. Together with compositional semantics, it tells us how to integrate the information given by lexical elements. Discourse relations indicate how to string together bits of spatiotemporal information into trajectories. Take for instance (3). Practically each clause therein provides a displacement from one position to another, but they are linked in a narrative sequence. If we use the axioms of Asher and Lascarides (2003) for Narration, we can link these together to get a trajectory of the author to the top of the mountain.

To go into just a few details, we need to say a bit about our model of discourse structure. We first isolate the basic units with which we will associate a feature structure involving one or more targets, a source a path and a goal (these may be empty if the segment does not contain any spatiotemporal information). Discourse relations manipulate or help us link these feature structures together. Narration, for instance, tells us that the goal of the feature structure of its first constituent should be identified with the source of the feature structure of its second constituent.⁴ There are also several types of Background relations. The relation of *S-Background* says that the eventuality described by the second argument spatio-temporally overlaps the location of the object denoted by the NP in the first constituent that the relative clause or modifier expressing the *S-Background* modifies. Thus, for the first two sentences of (3), we would get 4 basic segments, which we label here:

(3') [Suivre le sentier balisé (jaune)]₁ [qui remonte

⁴This is a slight simplification of the rules in (Asher and Lascarides, 2003).

la vallée de Leziou rive gauche dans la forêt.]₂
[Après une montée raide,]₃ [on débouche sur le plateau de Leziou (1662m) direction sud]₄.

We have for this part of the text: *S-Background*(1,2), *Narration*(1,3), *Narration*(3,4). Some of the parameters are not specified completely. Nevertheless, the combination of syntax, lexical semantics and discourse structure tells us quite a bit about the spatio-temporal structure of this text. Abstracting away from the specific details of the exact spatio-temporal relations conveyed by the prepositions here we will concentrate on verbs; the first and third verbs in the sequence specify a contact relation between target and landmark; the second specifies an internal relation relation while also conveying, along with the third verb, a certain directionality—up. The last specifies an external spatio-temporal relation between target and landmark. From this lexical information together with axioms about discourse structure, we can infer the following:

- Path₁ = le sentier balisé (jaune)
- e_1 and target spatially included within Path₁ at the time specified by eventuality e_1 .
- Source₂ = Path₁ (temporally unrestricted)
- Target in contact with Path₁ during eventuality e_1 .
- Source₂ included in Path₂ (temporally unrestricted).
- Path₂ = la vallée de Leziou rive gauche dans la forêt.
- Goal₁ = Source₃ at the temporal onset of e_3 (after e_3)
- Goal₃ = Source₄; target located there after e_3
- Goal₄ = le plateau de Leziou (1662m).
- Source₄ = Goal₄ (temporally unrestricted).
- target located at plateau de Leziou after e_3

We can thus follow the target's trajectory after each one of these events, and we can in principle answer queries like 'Where am I after I've climbed up the steep section?' Much more in terms of inference can be done here, given that we can link these surface features with the axiomatic mereo topology (Gerevini and Nebel, 2002; Wolter and Zakharyashev, 2000; Yaman et al., 2004).

Beside *S-Background* and *Narration*, other discourse relations like *Precondition*, *Explanation*, *Result* and *Elaboration*, have spatiotemporal consequences. We ignore other so called structural relations, featured in many theories of discourse analysis (Asher and Lascarides 2003). We plan to study the spatio-temporal consequences of these relations.

As within TimeML, we think it important to take account of modals, disjunctions, conditionals and negations in processing spatio-temporal relations conveyed by a text. Negations will be treated eliminating spatio-temporal information in their scope. Conditionals, disjunctions and various modal operators affect the status of the information within their scope as well.

7 Conclusion

Our detailed work on the lexical semantics of motion verbs and prepositions leads us to believe that the annotation of spatiotemporal information is crucial to understanding the spatial information in a text. While very much in the programmatic stage, we feel that we are close to having the tools needed to induced much of this spatiotemporal structure automatically. But only time will tell whether the ideas sketched here will bear the fruit we hope they will.

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