Wide-Coverage Semantics for Spatio-Temporal Reasoning

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ABSTRACT. *In this article, we describe our research on wide-coverage semantics for French-language texts and on its application to produce detailed semantic descriptions of itineraries. Using a categorial grammar semi-automatically extracted from the French Treebank and a manually constructed semantic lexicon, the resulting parser computes discourse representation structures representing the meaning of arbitrary text. The main goal of this paper is to apply and specialize this general framework of wide-coverage semantics to the spatial and temporal organization of the Itipy corpus — a set of 19th century texts discussing voyages through the Pyrenees mountains. The implemented system gives satisfying results and opens the door to the integration with specialized extensions, such as a separate module computing the discourse relations between the textual units.*

RÉSUMÉ. *Dans cet article, nous donnons une description de notre recherche sur la sémantique à large couverture pour le français et, plus précisément, de la façon dont ces expressions sémantiques sont utilisées pour donner l'interprétation spatio-temporelle des itinéraires. En utilisant une grammaire catégorielle extraite semi-automatiquement du French Treebank et un lexique sémantique construit manuellement, l'analyseur convertit les analyses syntaxiques en DRS (*discourse representation structures*). Le but principal de cet article est l'application et la spécialisation de cette méthodologie générale au corpus Itipy contenant des récits de voyage du 19e siècle. La chaîne de traitement complète donne des résultats tout à fait satisfaisants et laisse l'opportunité d'y ajouter des extensions spécialisées, comme un composant qui calculerait les relations discursives entre les parties du texte.*

KEYWORDS: *categorial grammar, itineraries, lambda calculus, Lambek calculus, spatial logic.*

MOTS-CLÉS : *grammaires catégorielles, itinéraires, lambda calcul, calcul de Lambek, logique spatiale.*

1. Introduction

In this article, we will discuss the application of wide-coverage semantics to give an analysis of travel itineraries. Doing so, we will touch upon many different themes: training the parser, transforming its analyses into Discourse Representation Structures, the logical framework for spatial analysis and the temporal framework.

1.1. *The Corpus*

The Itipy corpus is a collection of texts, containing several books mostly from the 19th century with a total of 576,334 words of text, describing voyages through the Pyrenees mountain range. In the context of the current paper, our goal is to adapt and specialize the methods of Moot (2010b) for wide-coverage semantics for French in order to obtain a semantic representation of the route followed.

1.2. *Informal Illustration*

Before going into the formal details, we will informally discuss an example from the corpus and the intuitive kind of meaning and, more specifically, the itinerary which corresponds to it. The following is a fragment from the start of the "Journal of James David Forbes". Though it is rather simple, it illustrates some of the basic points and at least some of the problems to be tackled in the rest of this paper — in the English translations, the verb tense will be annotated *PC* for *passé composé*, the perfect tense, denoting completed events in the past, *PS* for *passé simple*, the historic past tense, denoting punctual, completed events in the past and *IMP* for *imparfait* denoting ongoing, incomplete past events or past states.

(1)
a. 5 juillet.
July 5th
b. (...) Je suis parti à 11h1/4 avec un groupe de gens pour le phare de Cordouan dans une pinasse.
I left-PC at 11:15 with a group of people in a fishing boat for the Cordouan lighthouse.
c. (...) nous arrivâmes à Cordouan vers trois heures (...)
We arrived-PS at Cordouan around three o'clock.
d. Nous avons quitté Cordouan vers 5 heures.
We left-PC Cordouan around five o'clock.
e. Presque calme; nous avons mis deux heures pour arriver à Royan.
Almost calm; it took-PC us two hours to reach Royan.
f. J'y ai passé la nuit.
I passed the night there.
g. 6 juillet.
July 6th

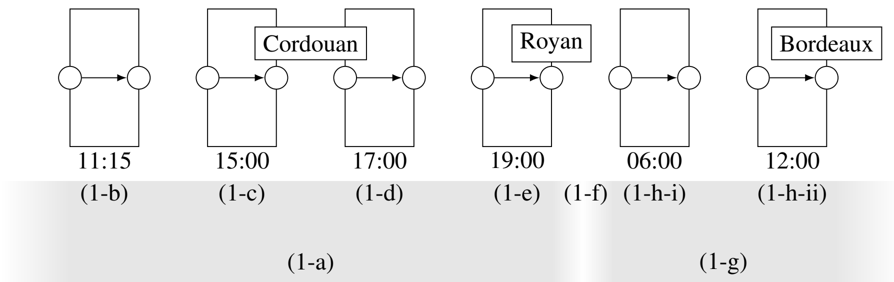


Figure 1. *The example sentences and their spatio-temporal consequences*

h. (i) Je suis parti par le bateau à vapeur à 6 heures du matin
I left-PC by steamboat at 6 in the morning
(ii) et j'ai atteint Bordeaux à midi après une brève traversée.
and I reached-PC Bordeaux at noon after a brief crossing.

The initial location is not specified in the text. Figure 1 shows a spatio-temporal interpretation of the discourse above.

A way to look at Figure 1 is as we would look at the panels of a comic book, [1] with each panel corresponding to a discourse unit, with associated temporal information (displayed below the panel) and spatial information (the arrows representing paths taken and the circles representing places visited). The information represented in each panel is very partial: in many cases, only the source or the destination of a change of location is mentioned. However, a default would be that, for consecutive events, when not contradictory with other information, all actors start each successive event from the place they ended the previous event. In Figure 1 this corresponds to pasting the panels together, identifying the left (starting) circle of one panel with the right (ending) circle of the previous. This simple operation suffices for the current example. From the point of discourse structure, Segmented Discourse Representation Theory (Asher and Lascarides, 2003) would assign the *Narration* relation to the consecutive discourse units (the black rectangles in the upper section of the figure) and the spatio-temporal consequences of *Narration* would give us exactly the inferences sketched informally above.

1. Fernando (2005) uses the same metaphor, though in Fernando's work the panels represent the temporal ordering of different events, whereas here the panels represent the different discourse units, with the order between these discourse units to be determined. In the current example, featuring mainly *Narration*, the difference is noticeable only in the two gray-shaded areas (1-a) and (1-g) representing the date indications. It is also worth noting that the prototypical narrative conventions of comics and other types of literature are different: few comic books would spend a panel giving background information about one of the previous panels. So, as with any metaphor, we must be careful in its application.

Though the discourse of Example (1) is simple, a few points are already worth noticing. Firstly, “partir pour” (*leave for*) in sentence (1-b), roughly speaking, only puts an intended destination on the stack of places to visit: leaving the current place with the intention of going to this destination is all that is required to satisfy the truth conditions of the sentence (it is an *intended goal* in the terminology of Moszkowicz, 2011). We can remove this destination upon arrival, which is usually mentioned in the text, or upon a change of plans and destinations, which is harder to detect.

Secondly, though they appear simple in the example, the date indications (1-a) and (1-g) — denoted by the gray-shaded boxes — can be problematic in when to decide the *end* of the day. Here, spending the night in sentence (1-f) is a clear indication that a day has passed, but authors are not always as conscientious with giving precise day-to-day accounts of their activities.

In addition, concluding that the arrival mentioned in Example (1-e) is at 19:00 requires some (simple) temporal reasoning: the departure was at 17:00 and arriving took 2 hours. Finally, though not problematic here, sentence (1-f) contains a spatial anaphor “là” (*there*) which may require resolution in order to determine the location.

1.3. *Roadmap to the Rest of This Paper*

Now that we have illustrated the general problem and reasoned intuitively with a simple example, the question we ask in the article is: how much of this reasoning can be performed automatically? Given a text, how do we determine who moved where and when?

A simple solution would be to simply use a gazetteer with place names and their location, strip away text not appearing in the gazetteer (perhaps with some additional pattern matching to remove place names occurring in certain contexts) and assume the resulting list of place names corresponds to the itinerary described; for the example discussed previously this strategy actually suffices!

A more ambitious solution, and the one we will adopt in the rest of this paper is to give a systematic analysis of the semantics of the phrases in the itinerary and construct a representation of the path taken during the course of the discourse. Recent developments in wide-coverage semantics (Bos *et al.*, 2004; Moot, 2010b) have shown that it is possible to construct deep semantic representations for arbitrary text and we will focus here on how to generate such representations for itineraries. To a large extent, this kind of research is possible by virtue of the close link between syntactic analysis and semantics in categorial grammars. Section 2 contains a (short) introduction to the syntax and semantics of multimodal categorial grammar, paying special attention to the syntax-semantics interface for verbs and spatio-temporal prepositions. Section 3 gives an overview of the components of the implementation. Section 4 will discuss the spatial logic used to represent locations, paths and their relations, whereas Section 5 will discuss the temporal aspects of the logic.

We will conclude by reflecting on what has been done so far, what remains to be done and we will discuss some directions of future research.

For reasons of space, we will assume the reader has at least a basic working knowledge of the lambda calculus, (modal) logic, (S)DRT, Allen's interval calculus, the Region Connection Calculus (RCC8) and has some very basic notions of topology.

2. Categorial Grammar

Categorial grammar in the logical tradition was initiated by Lambek (1958), who extended earlier results from Ajdukiewicz and Bar-Hillel by formulating his calculus as a *logic* — a rather restricted fragment of intuitionistic logic. The notation A/B, for a formula looking for a B formula to its right to form an A, and $B\backslash A$ for a formula looking to the left for a B to form an A was also introduced in Lambek's paper. Multimodal extensions of the logic, first introduced in the late 80s and early 90s, have increased the linguistic sophistication (Lambek's original calculus generated only the context-free languages) without sacrificing the logical nature of the calculus (for recent overviews of (multimodal) categorial grammars, see Moortgat, 2011; Morrill, 2011; Oehrle, 2011; Moot and Retoré, 2012).

The rules used for the large-coverage french grammar are shown in Table 1 (the rules are slightly condensed for ease of exposition, but readers familiar with multimodal categorial grammars will have no problems reconstructing the more explicit formulation; the grammar contains some additional rules for right-node raising, ellipsis and gapping which are not shown here — these rules are essentially those of Kurtonina and Moortgat (1997) for right-node raising, using lexically controlled associativity, and those of Hendriks (1995) for ellipsis using a combination of two extractions and a single infixation at the leftmost extraction site).

Basic statements are of the form $T \vdash F$ where T is a binary branching tree (with branches of the form $X \circ Y$ and words as leaves) and F is a formula. The lexicon rule allows us to conclude $w \vdash F$ if F is a lexical entry for the word w. To save space in a derivation, we will sometimes write this rule as $\frac{w}{F}$. The $/E$ and $\backslash E$ rules combine expressions: $/E$ combines a previously derived expression X with formula A/B (looking to its right for a B formula to form an A) with an expression Y which we have derived to be of type B. The tree combining X and Y as $X \circ Y$ is then of type A. Rule $\backslash E$ is the symmetric rule for formulas of the form $B\backslash A$.

The $/I$ rule, sometimes called *hypothetical reasoning*, is Lambek's addition to the previous Ajdukiewicz/Bar-Hillel calculus. It hypotheses a B formula (with an unused variable x) and uses this B formula to derive an A. Now, provided that the variable x assigned to B is the immediate right daughter from the root of the tree, we can withdraw our B hypothesis and conclude A/B. The $\backslash I$ rule is again symmetric.

The two final rules are long-distance variants of the other rules: compare $\backslash_1 E$ to $\backslash E$ and $/\Diamond\Box I$ to $/I$. The $\backslash_1$ rule states that when we have a tree Z of type $B\backslash_1 A$ and

$$\dfrac{}{w \vdash A}\ Lex \qquad\qquad \dfrac{}{x \vdash A}\ Hyp$$

$$\dfrac{X \vdash A/B \quad Y \vdash B}{X \circ Y \vdash A}\ /E \qquad\qquad \dfrac{X \vdash B \quad Y \vdash B\backslash A}{X \circ Y \vdash A}\ \backslash E$$

$$\dfrac{\begin{array}{c} x \vdash B \\ \vdots \\ X \circ x \vdash A \end{array}}{X \vdash A/B}\ /I \qquad\qquad \dfrac{\begin{array}{c} x \vdash B \\ \vdots \\ x \circ X \vdash A \end{array}}{X \vdash B\backslash A}\ \backslash I$$

$$\dfrac{X[Y] \vdash B \quad Z \vdash B\backslash_1 A}{X[Y \circ Z] \vdash A}\ \backslash_1 E \qquad \dfrac{\begin{array}{c} x \vdash B \\ \vdots \\ X[Y \circ x] \vdash A \end{array}}{X[Y] \vdash A/\Diamond\Box B}\ /\Diamond\Box I$$

Table 1. *Logical rules for multimodal categorial grammars*

$$\dfrac{\dfrac{\dfrac{\text{v}}{np} \quad \dfrac{\dfrac{\text{p}}{(np\backslash s)/(np\backslash s_{inf})} \quad \dfrac{\dfrac{\dfrac{\text{r}}{((np\backslash s_{inf})/pp_X)/np} \quad \dfrac{}{\text{x} \vdash np}}{\text{r} \circ \text{x} \vdash (np\backslash s_{inf})/pp_X}\ /E \quad \dfrac{\text{s}}{pp_{sur}}}{(\text{r} \circ \text{x}) \circ \text{s} \vdash np\backslash s_{inf}}\ /E}{\text{p} \circ ((\text{r} \circ \text{x}) \circ \text{s}) \vdash np\backslash s}\ /E}{\text{v} \circ (\text{p} \circ ((\text{r} \circ \text{x}) \circ \text{s})) \vdash s}\ \backslash E \quad \dfrac{\text{e}}{s\backslash_1 s}}{\text{v} \circ (\text{p} \circ (((\text{r} \circ \text{e}) \circ \text{x}) \circ \text{s})) \vdash s}\ \backslash_1 E}{\text{v} \circ (\text{p} \circ ((\text{r} \circ \text{e}) \circ \text{s})) \vdash s/\Diamond\Box np}\ /\Diamond\Box I$$

Figure 2. *Example derivation of "[une empreinte que]* ***v****ous* ***p****ouvez* ***r****emarquer* ***e****ncore* ***s****ur ce bloc de granit"*

a tree X containing a distinguished subtree Y (noted as $X[Y]$), then we can insert Z to the right of Y in the initial tree. The $/\Diamond\Box I$ hypothesizes a B as before, but now allows us to derive A containing x on a right branch somewhere inside of the tree (not necessarily as a daughter of the root).

Figure 2 shows an example derivation; "remarquer" (*remark*) is a verb requiring both an object and a locative preposition, here "sur ce bloc de granit" (*on this granite slab*), condensed in the proof as **s**. The word "que" (*that/which/whom*), not shown in the derivation, has as type $(n\backslash n)/(s/\Diamond\Box np)$, which intuitively means it is looking for a sentence missing a noun phrase to its right, then for a noun to its left to form a noun. Figure 2 shows how to derive an $s/\Diamond\Box np$ in this context, by hypothesizing a noun phrase, then deriving a sentence and finally withdrawing the hypothesis. Since x is

$$\dfrac{\dfrac{\dfrac{\dfrac{v}{np} \quad \dfrac{\dfrac{p}{(np \Rightarrow s) \Rightarrow (np \Rightarrow s)} \quad \dfrac{\dfrac{\dfrac{r}{np \Rightarrow (pp \Rightarrow (np \Rightarrow s))} \quad \overline{x : np}}{(r\ x) : pp \Rightarrow (np \Rightarrow s)} \Rightarrow E \quad \dfrac{s}{pp}}{((r\ x)\ s) : np \Rightarrow s} \Rightarrow E}{(p\ ((r\ x)\ s)) : np \Rightarrow s} \Rightarrow E}{((p\ ((r\ x)\ s))\ v) : s} \Rightarrow E \quad \dfrac{e}{s \Rightarrow s}}{(e\ ((p\ ((r\ x)\ s))\ v)) : s} \Rightarrow E}{\lambda x.(e\ ((p\ ((r\ x)\ s))\ v)) : np \Rightarrow s} \Rightarrow I$$

Figure 3. *The intuitionistic proof and lambda term corresponding to Figure 2.*

not the leftmost daughter of the root node, using the more general $/\Diamond\Box I$ rule (instead of simply the $/I$ rule) is required.

2.1. *Categorial Grammar and Semantics*

Since categorial grammars are a restricted fragment of intuitionistic logic and proofs of intuitionistic logic correspond, via the Curry-Howard isomorphism, to simply typed lambda terms, the link between categorial grammar and formal semantics in the tradition of Montague is very direct. Figure 3 shows the intuitionistic proof and the lambda term corresponding to the previous example derivation.

The lambda term corresponding to the proof has one occurrence of every free variable (corresponding to the words from the lexicon). If we replace these variables with lexical lambda terms of the same type and reduce the resulting lambda term, we have integrated the core of Montague semantics into categorial grammar and we can extend this very simple semantics to more modern semantics theories like discourse representation theory (DRT, Kamp and Reyle, 1993; Kamp *et al.*, 2011) as well. Though the wide-coverage semantics implemented here uses DRT (Moot, 2010b), we will, for reasons of space and simplicity, mostly use Montague-style lexical semantics in this article.

2.2. *Verbs and Sorts*

As we discussed elsewhere (Moot *et al.*, 2011), we use different sorts to distinguish between different types of entities: persons, places, paths, eventualities, etc. Verbs select for specific types of arguments: for example, a verb like “go to” requires a place as an object. A mechanism of coercion or type-shifting in the style of Pustejovsky (1995) can in some cases change the type in a lexically determined way. So when “go to” takes a person as its object (whereas it requires a place) this can mean that we go to the place where this person is. Given that type coercion is not a major topic of this article, we use the simpler strategy of a sense-enumeration lexicon and refer the interested reader to Moot *et al.* (2011) for details as to how a coercion strategy can be implemented in categorial grammar.

Motion verbs will be instances of the predicate $\textit{travel}(e, x)$ where e is a Davidsonian eventuality argument and x is the moving entity. Two functions *path* from eventualities to paths [2] and *time* from eventualities to times give us the time interval during which the movement takes place and the path taken by the moving entity. The intended meaning is that x moves along $\textit{path}(e)$ during $\textit{time}(e)$, with a linear function with positive slope relating the time and the path position of x; we will discuss our spatial and temporal primitives more precisely in Sections 4 and 5 respectively.

Locative prepositions can occur both as arguments (such as in the example above) and as modifiers to the verb and the difference is slightly subtle: if a locative preposition is used adverbially, the entire eventuality takes place inside the region denoted by the np argument of the preposition. On the other hand, if a locative preposition is an argument of the verb, the lexical semantics of the verb will specify the combined meaning (this is essentially the same strategy as Nam (1995)). Sometimes, both are possible. So the following sentence, taken from Asher and Sablayrolles (1995), has two possible readings: one where all running takes place on the football field and one where the players run *onto* the football field.

(2) Les joueurs courent sur le terrain de football.
The players are running on/onto the football field.

Another way to state this distinction is to say that "sur le terrain de football" is ambiguous between a *region* interpretation and a *path* interpretation (as done by e.g. Jackendoff (1983); "sur NP" in its path interpretation would denote a partial description of a path, specifying only that it ends on the np region).

To give an idea of the form of the lexicon, some schematic lexical entries are shown below. More refined entries will follow in the next sections, when we have been more precise about the spatial primitives.

suivre	$(np\backslash s)/np$	$\lambda p_{\textit{path}} \lambda x_{\textit{person}} \lambda e.\textit{travel}(e, x) \wedge \textit{path}(e) \subseteq p$
suivre	$(np\backslash s)/np$	$\lambda y_{\textit{person}} \lambda x_{\textit{person}} \lambda e.\textit{travel}(e, x) \wedge \textit{travel}(e, y)$
courir	$np\backslash s$	$\lambda x_{\textit{person}} \lambda e.\textit{travel}(e, x)$
courir	$(np\backslash s)/pp$	$\lambda p_{\textit{path}} \lambda x_{\textit{person}} \lambda e.\textit{travel}(e, x) \wedge \textit{path}(e) = p$
sur loc	$s\backslash_1 s$	$\lambda s \lambda e.(s\ e) \wedge \textit{path}(e) \subseteq \text{loc}$
sur loc	$pp_{\textit{sur}}$	p *is a path ending on* loc

2. Not all eventualities have paths in the spatial sense which interests us here, e.g. in a sentence like "The Down Jones fell during much of the session on Monday", so either *path* is a partial function or we need a two distinct types of eventualities, with *path* being a total function for one of these types.

2.3. *Beyond Motion Verbs*

Though motion verbs have been amply studied in the literature on the semantics of itineraries, in many cases movement is implied without an appeal to motion verbs.

(3) a. J'ai dîné confortablement à Gèdre.
I dined-PC comfortable at Gèdre.
b. Mont-de-Marsan, où nous avons soupé, est une ville importante dont les alentours semblent agréables.
Mont-de-Marsan, where we dined-PC, is an important town the surroundings of which seem pleasant.

In the text just before Example (3-a), it has been established that the author has been traveling in the valley of Héas and after this sentence we infer without problem that he has arrived in Gèdre before dining there. [3]

The main clause of Example (3-b) is a stative sentence, describing properties of the village of Mont-de-Marsan. However, the relative clause headed by "où" (*where*) indicates the authors had dinner there, which, much like Example (3-a), allows us to conclude that the author arrived in Mont-de-Marsan without explicitly stating this. These examples — and they are quite frequent in the corpus — show the benefits of full syntactic/semantic analysis as advocated in this paper.

Given the basic assumptions stated above: that eventualities have a path argument and that, when used adverbially, locative prepositional phrases contain the path corresponding to the eventuality they modify, the correct semantic analysis is a simple and direct consequence of the representation chosen.

3. Components

The implementation described in this paper is part of a larger system for wide-coverage semantics for French, with the semantics of itineraries being a specific application. The complete system consists of a part-of-speech (POS) tagger, a supertagger, a Named Entity Recognition (NER) module (these three components are those of Clark and Curran (2004), trained on French data), a parser and a semantic lexicon.

3.1. *Part-of-Speech Tagger*

An effort has been made to make life easy for the POS-tagger, meaning that the POS-tagger is meant to help the supertagger as much as possible but to leave certain difficult decisions to the supertagger in case a POS-tag error is hard for the supertagger

3. This inference is valid only if the sentence is in the discourse relation of *Narration* with a sentence in an established itinerary.

FTB	**TreeTagger**	
V	VER:pres	present
V	VER:simp	simple past
V	VER:impf	imperfect
V	VER:futu	future
V	VER:cond	conditional
VS	VER:subp	subjunctive present
VIMP	VER:impe	imperative
VINF	VER:infi	infinitive
VPR	VER:ppre	present participle
VPP	VER:pper	past participle
DET	NUM	number, used as determiner
ADJ	NUM	number, used as adjective
NC	NUM	number, used as common noun
PRO	NUM	number, used as pronoun
DET	PRP:det	preposition used as determiner, e.g. “du”
ADJ	VER:pper	past participle used as adjective

Table 2. *Main differences between the FTB and TreeTagger tagsets used to annotate the corpus*

to correct. As an example, the french word “du” can be used both as a determiner (corresponding to the empty determiner in English, with most frequent formula np/n) and as a preposition/determiner combination (“du” is a contracted form of “de + le” (*of the*), with most frequent formula pp_{de}/n). Though a correct POS-tag helps the supertagger, a POS-tag error (and these are frequent enough to be bothersome) can prevent the supertagger from selecting the correct formula, given that the erroneous POS-tag biases the formula assignment. A choice has been made to assign these words the POS-tag PRP:det systematically, essentially leaving it up to the supertagger to select the correct formula. Similar arguments apply to the numbers, which can function as determiners (np/n), adjectives (n/n or $n\backslash n$), common nouns (n or np) and pronouns (np).

On the other hand, the verb annotation, V in the French Treebank, has been split up into the different verb forms listed in Table 2. We will see in Section 5 that the verb inflection plays an important role in determining the temporal relations between phrases in the text.

The POS-tagger trained on the French Treebank data (plus the additions described below) gives very accurate tags: 98.4% with the TreeTagger tagset described above, using tenfold cross-validation. Some of the remaining difficulties are the word “que” which functions as a relative pronoun, as a complementizer and as an adverb (though the supertagger generally recovers from POS-tag errors in these cases) and infrequent cases where a determiner-noun sequence is incorrectly analyzed as a clitic-verb sequence or inversely (which are much harder for the supertagger to correct).

Though the POS-tagger is highly effective on newspaper articles — such as *Le Monde*, both in the FTB and in current issues, and *L'Est Républicain* — early tests with the Itipy corpus brought to light several weaknesses of the POS-tagger. For example, the word "marché", which is ambiguous between a common noun, meaning "market", and a past participle meaning "walked", occurs exclusively in the sense "market" in the French Treebank but has many occurrences in the sense "walked" in the Itipy corpus; this makes sense given the economic coverage in the FTB and the description of itineraries in the Itipy corpus, but it means that the POS-tagger has a strong preference for assigning a noun category to the word "marché" even when this is contextually unlikely, for example in a verbal complex such as "a marché" (*has walked*). Another problematic word is the second person singular "tu" (this is the familiar form, opposed to the formal "vous") which occurs only 4 times in the FTB (spelled in three different ways). Again, this is expected for a newspaper corpus, but not for a corpus consisting at least partly of letters to friends and family.

A final problem is the frequent occurrence of *passé simple* verbs in first person plural in the Itipy corpus. In a first-person narrative, of which there are many in the Itipy corpus, these forms are rather common. However, in the FTB there are no occurrences of the first-person plural *passé simple* at all. Since the POS-tagger chooses tags for unknown words based on suffix information (in addition to the information provided by the surrounding words) and the suffixes for these forms have not been seen in the training data, this makes it rather likely that an incorrect POS-tag (present tense is the most common) is assigned.

In order to remedy both of these problems, a number of sentences from the Itipy corpus (820 sentences, with a total of 22,018 words) have been manually annotated with POS-tag information and the POS-tagger has been retrained with this new data.

3.2. *Supertagger*

As shown by Moot (2010a), the wide-coverage categorial grammar used here has been semi-automatically extracted from the French Treebank (Abeillé *et al.*, 2003). However, given that the extracted lexicon is both too large (in the sense that it assigns too many formulas to many frequently occurring words, making the lexicon size an important bottleneck to parsing) and too small (in the sense that many other words do not occur in the lexicon at all, resulting in insufficient coverage), a supertagger is used to solve both problems.

A supertagger is like a POS-tagger, but with a much richer tagset — in our case a set of over 900 formulas — hence *supertagging*. The supertagger assigns, given the context, the most likely formula to each word in a sentence. The context consists of the word itself (provided it has been seen more than five times in the training data), the previous two words, the next two words as well as the POS-tags for all five words in the context. In addition the supertagger uses the supertags (formulas) chosen for the previous two words.

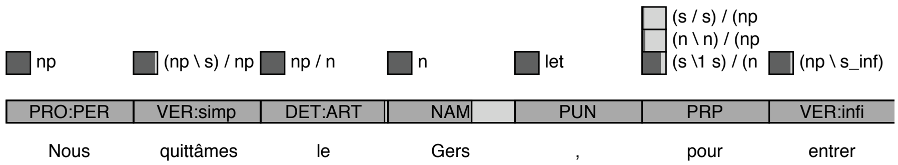


Figure 4. *POS-tagger and supertagger results for Sentence (4)*

For unknown words, the POS-tag and context information allow the supertagger to make an educated guess about the correct formula. For highly lexically ambiguous words, the supertagger gives what it considers the most likely formula for the current context.

The supertagger has been trained on the annotated data, which contains 412,966 word tokens (14,143 sentences) and 42,195 word-POS-formula types, with an average number of lexical entries of 7.2 for words occurring 100 times or more in the corpus.

The supertagger assigns 90.2% of all words the correct formula using tenfold cross-validation. Though this score compares well with other supertaggers, it still means that less than one sentence in four is given the correct sequence of supertags, and — though not having all supertags correct does not necessarily mean the sentence cannot be parsed, just that its parse will at least have some errors — this means that the coverage of the parser is rather limited. A standard solution is to assign a *set* of supertags to each word, thereby increasing the coverage of the parser. I have adopted the solution of Clark and Curran (2004) in selecting all formulas to which the supertagger assigns a probability greater than a certain percentage of the best supertag. This means, in general, that the supertagger proposes more supertags for difficult words. With a beta value of 10%, supertag accuracy becomes 96.4%, with a beta value of 1%, supertag accuracy becomes 98.4%, though it assigns 2.4 formulas on average to each word (which is still a significant reduction over the 7.2 average for frequent words).

Figure 4 gives the results for the POS-tagger and the supertagger for the following sentence (with a beta value of 10%):

(4) Nous quittâmes le Gers, pour entrer dans les hautes pyrénées .
We left-PS the Gers (region), in order to enter the Hautes Pyrenees (region).

Note that the number of formulas assigned to each word stays quite reasonable: the verbs "quittâmes" (*left* in passé simple) and "entrer" (the infinitive *to enter*) are assigned only a single and correct formula, a simple transitive verb for the first and an infinitive with a *pp* object for the second. The prepositions "pour" (*in order to* + infinitive), has multiple formulas assigned to it, but with 80.5% confidence in the correct formula $(s\backslash_1 s)/(np\backslash s_{inf})$.

3.3. *Named Entity Recognition*

The treatment of prepositions is rather difficult. A simple solution would be to give a preposition like "à" with formula $(n\backslash n)/np$ a semantics like $\lambda x \lambda P \lambda y.\grave{a}(x, y) \wedge P(y)$. However, this will suffice neither for our temporal nor for our spatial predicates: constructions of the form "à + location" and "à + time" need special and distinct treatments (see Sections 4 and 5 for details). In addition, some verbs are dependent on the time/space distinction for their semantics as well: "passer + location" means "to go past/through", but "passer + time" means "to pass the time (somewhere)". But then the problem becomes: how to identify these temporal and spatial noun phrases?

A partial solution to this problem is to use an additional Named Entity Recognition (NER) component which identifies spatial named entities (toponyms) and temporal expressions. Even though there are many expressions other than named entities which can be used to refer to regions of space, this approximation works well enough in practice.

A cross-section of 3,027 sentences (84,164 words) from the FTB and the Itipy corpus (with a bit over half stemming from the Itipy corpus) has been annotated with NER data: tags used are ⟨person⟩, ⟨organization⟩, ⟨location⟩, ⟨time⟩, ⟨money⟩ and ⟨percentage⟩. The tags which will interest us here are ⟨location⟩, ⟨time⟩ and, to a lesser extent ⟨person⟩. Though the NER component would benefit from more annotated data (which would permit at least some evaluation; a typical NER module is trained on millions of words and though 84,164 seems like a reasonable number of words, 87.4% of these words are outside of named entities), the results of the current, very small dataset are rather promising.

3.4. *The Grail Parser and Its Semantic Lexicon*

The Grail parser is a general parser for multimodal categorial grammars. Integrated with the other components of the system, it can be used for wide-coverage parsing for French (Moot, 2010b). The current incarnation of the parser, in combination with the supertagger with $\beta = 1\%$ analyzes 87.5% of the sentences in the Itipy corpus (tested on 6,838 sentences with a total of 152,151 words). This is still slightly unsatisfactory and work is currently underway to improve this figure, using an extension of the results of Sandillon-Rezer (2012) (in addition, it is worth looking at incorporating modern statistical parsing methods as proposed by Djordjevic *et al.* (2007) and Auli and Lopez (2011)), but also by annotating more of the Itipy corpus, since many of the remaining errors are due to stylistic differences between newspaper texts and the more literary itineraries.

As discussed in Section 2.1, all that is missing to obtain lambda terms or DRT semantics from the derivations is a big enough lexicon giving the lambda terms for enough words.

Here, we use a very simple strategy (similar to Bos *et al.* (2004)): for closed-class words, such as the auxiliaries "être" (*to be*) and "avoir" (*to have*), words like "et" (*and*) but also for raising/versus control verbs and for verbs with factive, veridical and non-veridical complements, which are assigned the same formulas but not the same meanings, the lexicon assigns specific lambda terms according to both their formula and their lexical lemma. However, open-class words, such as common nouns, have a general lexicon schema: if w is a common noun with formula n assigned to it and it is not treated by one of the more specialized rules, we give it the semantics $\lambda x.w(x)$, and if w is a transitive verb with formula $(np\backslash s)/np$, the lambda term $\lambda y \lambda x.w(x,y)$ is assigned to it.

A treatment of presuppositions handles proper names and definite descriptions, but also some motion verbs like "quitter + loc " (*to quit*) which presuppose that the subject is at the location specified by the object.

The semantic lexicon currently contains 481 lexical entries, 346 default rules (which include listed verb types such as factive verbs and weather verbs) and 37 multi-word sequences.

An advantage of this setup is that the addition of a spatio-temporal component is fairly modular and simple: the tense information on a verb is treated orthogonally to its truth-conditional semantics, there are less than 30 motion verbs in the system, most following systematic recipes as described below (Asher and Sablayrolles (1995) have over 200 motion verbs in ten categories, and it would be interesting to add their list to the current system, though this restricted set of motion verbs handles most cases encountered in the corpus), and fairly short lists of spatial and temporal prepositions and adverbs, which we will illustrate with examples below.

4. Spatial Semantics

The approach to spatial semantics described here shares many points of its design philosophy with Asher and Sablayrolles (1995), Nam (1995), Zwarts (2005), Pustejovsky and Moszkowicz (2011) and with the forthcoming ISO-Space standard (Pustejovsky *et al.*, 2011) (ISO-Space has a number of additional features which are not incorporated here: e.g. cardinal directions "North" and spatial relations "behind", "to the left of"). The main innovation is its connection to standard spatial logics.

There are two basic types of spatial objects: regions and paths (with points in space playing a small auxiliary role):

regions are regular closed sets in Euclidean space $\mathbb{R}^3$,

paths are continuous maps from the unit interval $[0,1]$ to the Euclidean space $\mathbb{R}^3$. If p is a path, p starts at $p(0)$ (its source) and ends at $p(1)$ (its destination).

The definition of path is essentially the one used by Zwarts (2005) and is the classical definition from topology. It poses very few constraints on the shape of paths: paths can pass the same point many times, etc. and we think this is desirable. The connection between paths and times is that of a monotonically increasing function [4]: that is to say if $p(i)$ and $p(j)$ are positions on the path then if $i < j$ this means that the time corresponding to i is before the time corresponding to j. In fact, the temporal interval corresponding to the domain $[0, 1]$ of the path of an eventuality is a linear function with positive slope. However, this property is not preserved under concatenation since different eventualities have different durations.

As is well-known (see e.g. Theorem 51.2 of Munkres, 2000), paths in topological spaces behave very much like groups, with the group product '·' being path concatenation (the important difference with a group is that the group product is defined for *any* two elements, whereas here the product/concatenation is defined only when the final point of the first path is equal to the initial point of the second path), the identity element is the identity path 1_x (the constant function from $[0, 1]$ to x) and the inverses are the reverse path of p, denoted p^{-1} (by defining $p^{-1}(i)$ to be $p(1 - i)$). q is a subpath of p (we will sometimes write $q \subseteq p$ when it is clear from the context that p is a path) in case there are p_1 and p_2 such that $p = p_1 \cdot q \cdot p_2$ (see also Theorem 51.3 from Munkres, 2000).

Points play a role in our spatial theory only for determining heights and for relating paths to regions. That is, when p is a path and r is a region, formulas of the form $p(i) \in r$ are allowed. In addition, h is a function indicating the height of a point, which gives the projection to the z coordinate of a point on a path, typically used in expressions of the form $h(p(i))$.

The standard Euclidian metric d is used for the distance between two points. The distance between two regions and between a region and a point are defined as the distance to the closest point(s) in the region(s) [5] — the point y in the region which minimizes $d(x, y)$ for x, or the points x, y in the two regions which minimize $d(x, y)$ — and therefore 0 for points inside the region and for two overlapping regions.

To make path terms easier to read, we will use *start*(e) and *end*(e) as abbreviations for $(\textit{path}(e))(0)$ (the starting point of the path associated with event e) and $(\textit{path}(e))(1)$ (the end point of the path corresponding to e) respectively.

Some words can be immediately defined using the notions of height and distance defined so far, without the predicates for talking about regions introduced in the next section. "s'approcher de" (*approach*) requires in its truth conditions that the end of the path followed is closer to the object y than the start of the path. Note that the lexical semantics given below, in combination with the above definition of distance between

4. Technically, a convex piecewise linear function, which in addition is monotonically increasing.

5. In some contexts, it is more natural to talk about the distance to the *center* of a region, especially when discussing the distance between two regions and in many cases (e.g. on road signs) distance is measured in terms of the length of the most prominent *path* between two regions.

points and regions, makes "s'approcher de" automatically false in case the voyager x is already inside the target region y.

s'approcher de	$(np\backslash s)/np$	$\lambda y \lambda x \lambda e.\mathit{travel}(e,x) \wedge d(\mathit{start}(e),y) < d(\mathit{end}(e),y)$
vers loc	$(s\backslash_1 s)/np$	$\lambda r \lambda s \lambda e.(s\ e) \wedge d(\mathit{start}(e),r) < d(\mathit{end}(e),r)$
descendre	$np\backslash s$	$\lambda x \lambda e.\mathit{travel}(e,x) \wedge h(\mathit{start}(e)) < h(\mathit{end}(e))$

The preposition "*vers* + locative" (*towards*) is the adverbial variant of "approach": its truth conditions require only that the end of the path is closer to the locative noun phrase than the start of the path. The verb "descendre" (*descend*) is similar to "approach" except that it requires a decreasing height.

4.1. *Regions and Spatial Logic*

As a logic for reasoning about regions in space, we essentially use the logic $S4_u$ [6] (discussed e.g. in Aiello and van Benthem, 2002; Gabelaia *et al.*, 2005), extended with a connectedness predicate, a system equivalent to the one presented by Kontchakov *et al.* (2008) (though with some notational changes to make the correspondence with $S4_u$ more direct).

Spatial regions which have a proper name in natural language (France, the Gironde department, the Garonne river and the Pyrenees mountains) are constants in the set a of atomic regions. Atomic regions are regular closed regions (that is, every atomic region r is equal to the closure of its interior $r = \text{CI}r$, meaning, for a 2-dimensional object, roughly that the region has no trailing lines or points; as a consequence each atomic region includes its frontier by definition). Given this set a of atomic regions, the set of *basic* regions b is defined as follows:

$$b ::= 0 \mid 1 \mid a \mid b^c \mid b \Cup b \mid b \Cap b$$

The basic terms, with 0 denoting the empty region and 1 denoting the universe are the boolean algebra of regular closed regions, where t^c is the closure of the complement $\text{C}(t^{\complement})$, $t_1 \Cap t_2$ is defined as $\text{CI}(t_1 \cap t_2)$ (in order to guarantee that the result is again regular closed) and $t_1 \Cup t_2$ is simply equal to $t_1 \cup t_2$.

From the basic terms, *terms* denoting regions of space (not necessarily regular closed regions) are formed as follows, using the usual interior, closure, complement, union and intersection operations:

6. The modal logic $S4$, extended with a "universal modality" u which allows us to require (in the object language) that a formula is true in all worlds of the model, or, interpreted topologically, that a formula represents the entire topological space. In this logic, $\Box$ is interpreted as the topological interior and $\Diamond$ as the topological closure.

$$
\begin{array}{rcl}
p \vee q & = & \neg(\neg p \wedge \neg q) \\
dc(t) & = & \neg c(t) \\
\textit{frontier}(t) & = & (\mathrm{I}t)^{\mathsf{C}} \cap \mathrm{C}t \\
\neg(t = 1) & = & t \neq 1 \\
t^{\mathsf{C}} = 1 & = & t = 0 \\
\neg(t^{\mathsf{C}} = 1) & = & t \neq 0 \\
t \subseteq u & = & t^{\mathsf{C}} \cup u = 1 \\
t \nsubseteq u & = & t^{\mathsf{C}} \cup u \neq 1 \\
\hline
\mathrm{DC}(t,u) & = & t \cap u = 0 \\
\mathrm{EC}(t,u) & = & t \cap u \neq 0 \wedge \mathrm{I}t \cap \mathrm{I}u = 0 \\
\mathrm{PO}(t,u) & = & \mathrm{I}t \cap \mathrm{I}u \neq 0 \wedge t \nsubseteq u \wedge u \nsubseteq t \\
\mathrm{EQ}(t,u) & = & t \subseteq u \wedge u \subseteq t \\
\mathrm{NTPP}(t,u) & = & t \subseteq \mathrm{I}u \wedge u \nsubseteq t \\
\mathrm{TPP}(t,u) & = & t \subseteq u \wedge t \nsubseteq \mathrm{I}u \wedge u \nsubseteq t
\end{array}
$$

Table 3. *Defined predicates and the RCC8 relations*

$$t ::= b \mid \mathrm{I}t \mid \mathrm{C}t \mid t^{\mathsf{C}} \mid t \cup t \mid t \cap t$$

Finally, the spatial *predicates*, denoting truth values are the following:

$$p ::= c(t) \mid t = 1 \mid \neg p \mid p \wedge p$$

$t = 1$ corresponds to the universal modality (requiring the evaluation of a region formula to correspond to the entire universe). Though this is an apparent restriction on formulas — we allow the universal modality to appear only *outside* the other modal operators (interior and closure) — Aiello and van Benthem (2002) show that there is a simple truth-preserving formula translation which transforms any formula into a formula inside the current fragment.

Using these definitions and given two regions p and q, the subset relation $p \subseteq q$ can be defined as the formula $p^{\mathsf{C}} \cup q = 1$, stating that the union of p's complement with q is equal to the universe (all points are "outside of p" or "inside q"; this is essentially the definition of implication in terms of negation and disjunction). Similarly, equality can be defined as $(p \subseteq q) \wedge (q \subseteq p)$. Table 3 gives some more standard abbreviations, showing, in addition, that the RCC8 relations can all be expressed (and thereby treated as abbreviations). For example when two regions are disconnected (DC), this simply means that they have an empty intersection, whereas two externally connected (EC) regions do not have an empty intersection, but their interiors do have an empty intersection (in other words, their intersection contains only points on the respective frontiers of the two regions).

RCC8c (RCC8 with connectedness) is the sub-logic obtained by restricting the terms to (regular closed) atomic regions. Restricting terms to basic terms results in the logic BRCC8c (B for boolean, since the logic permits boolean combinations of atomic regions), extending the expressivity of the language in interesting ways.

Formula 1 below states that France is the union of continental France and the isle of Corsica and that these two regions are disconnected. Note, however, that this construction does not allow us to define disconnectedness in general, as the connectedness predicate allows us to do, since $dc(x)$ would correspond to $\exists y \exists z.\mathrm{EQ}(x, y \cup z) \wedge \mathrm{DC}(y, z)$ and this is a quantifier-free fragment. [7] The boolean combination of regions allows us to express disconnectedness only when the names (constants) for the disconnected parts are known.

$$\mathrm{EQ}(\mathit{France}, \mathit{ContinentalFrance} \cup \mathit{Corsica}) \wedge \mathrm{DC}(\mathit{ContinentalFrance}, \mathit{Corsica}) \quad [1]$$

$$\mathrm{EC}(\mathit{France} \cap \mathit{Pyr}, \mathit{Spain} \cap \mathit{Pyr}) \wedge \mathrm{DC}(\mathit{France} \cap \mathit{Pyr}^{\complement}, \mathit{Spain} \cap \mathit{Pyr}^{\complement}) \quad [2]$$

Formula 2 gives another way to exploit the extra expressivity of BRCC8: we can (essentially) say that frontier of Spain and France runs trough the Pyrenees. Formula 2 states that France and Spain are externally connected at the shared region of the Pyrenees and that the parts of France and Spain outside of the Pyrenees are disconnected.

The full expressivity of $S4_u$ is still strictly more powerful: for example, given a region term t, the term $(\mathrm{I}t)^{\complement} \cap \mathrm{C}t$ denotes its frontier (the points which are in the closure of p but not in its interior, one of the standard ways to define frontiers in topology). Though in our application, there is little use of this extra expressivity, $S4_u$ is, in a sense, the most natural logical calculus which can be used for spatial reasoning.

4.2. *Paths and Regions*

Though we have seen above that the semantics of verbs can be expressed directly by properties of the paths, it is rather difficult to reason about paths — even for topologists, and the topological restriction to paths where the source is the same point as the destination is rather inappropriate for itineraries. Therefore, we propose a translation of paths into regions which allows us to reason about paths directly in the spatial logic $S4_u c$ introduced in Section 4.1. Though this connection between paths and regions is slightly involved, I think it is essential to be able to reason about paths and regions in a single logical framework (though there are some systems of reasoning which have both paths and regions, such as the 9+ intersection model of Kurata and Egenhofer

7. Natural language contains some expressions which seem to call for quantification over places, e.g. "partout" (*everywhere*), "quelque part" (*somewhere*), "nulle part" (*nowhere*), however we are not convinced that, in the presence of arbitrary unions and arbitrary intersections (using $S4$ requires us to interpret regions in Alexandrov space), there is any need to explicitly quantify over regions.

(2007) formulated in algebraic topology, our choice for the current solution is motivated by the desire to do as much reasoning as possible in our logical framework). In addition, as we will see in the next section, the proposed solution simplifies the formulation of verb semantics and the notion of path equivalence allows us to give a rather simple semantics to verbs like "suivre" (*follow*, refining the previous semantics) and "longer" (*to go along*).

A path p has an associated region, called its *extension*, *ext*(p), which is a connected regular closed space such that the range of the path is properly included in this region. The actual size of the extension of a path is contextually determined; when walking along a road, the extension of this path typically includes at least the width of the road — though when walking with a 3-year-old, it will be restricted to the sidewalk of the road and crossing to the sidewalk on the other side will be an important event.

Following Asher and Sablayrolles (1995), the extension of a path is divided into three regions, the *initial* region (containing $p(0)$), the *middle* region (containing at least some $p(i)$ for $0 < i < 1$, this is the strict internal path (SIP) of Asher & Sablayrolles) and the *final* region (containing $p(1)$). Taking this idea as a basis, the following definition suggests itself:

a *simple path* is a path p with extension x such that:

$$\textit{simple\_path}(p) =_{\textit{def}} \quad \textit{ext}(p) = x \wedge \mathrm{EQ}(x, S_x \cup M_x \cup G_x) \wedge \mathrm{DC}(S_x, G_x) \wedge$$
$$\mathrm{EC}(S_x, M_x) \wedge \mathrm{EC}(M_x, G_x) \wedge c(S_x) \wedge c(M_x) \wedge c(G_x) \wedge p(0) \in S_x \wedge p(1) \in G_x$$

Figure 5a should help visualize the spatial relations between S_x, M_x and G_x. It stands to reason that the extension of a path is connected (though not necessarily *path-connected*, since we allow paths containing cycles which have extensions containing holes). Here, we use a stronger condition that all three components are connected, excluding cases like Figure 5b, where the region as a whole is connected but the individual subregions are all disconnected.

Given $\mathrm{DC}(S_x, G_x)$, it follows that any path from S_x to G_x must pass through M_x or, more formally, there is an i such that $p(i) \in M_x$.

However, the definitions given above still leave a lot of freedom, allowing a path to zig-zag between the three distinct parts of the extension — though when combined with the verb semantics of the next section, this will be resolved by assigning intuitive meaning recipes to the verbs. Figure 5c shows an example of a path which goes back and forth between S_x and M_x, which might not be the preferred meaning for a verb like "leave". Instead of leaving this to verb semantics, it seems more natural to require paths to be *nice* with respect to their extensions as defined below. That is, they have an initial segment inside S_x, a middle segment inside M_x and a final segment inside G_x.

$$\textit{nice}(p) =_{\textit{def}} \underset{0<i<j<1}{\exists i \exists j} . \underset{0<k<i}{\forall k} . \, p(k) \in S_x \wedge \underset{i<k<j}{\forall k} . \, p(k) \in M_x \wedge \underset{j<k<1}{\forall k} . p(k) \in G_x$$

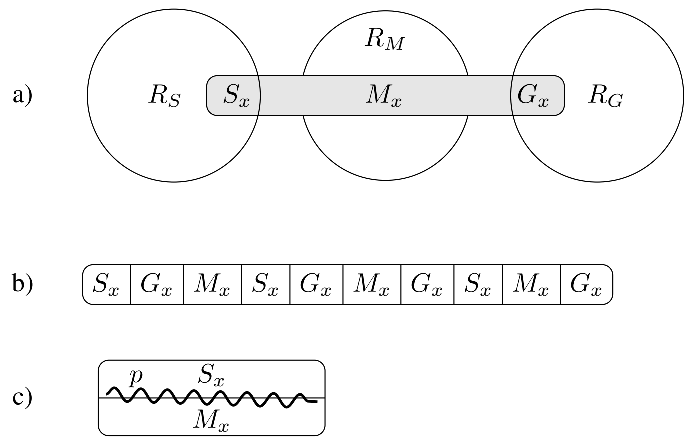


Figure 5. *a) The extension of a path and its relation to the region arguments of initial, medial and final verbs and prepositions*
b) A connected path extension with disconnected S_x, M_x and G_x
c) The regions S_x and M_x of a not-so-nice path

Given that it will quickly become cumbersome to refer to the different regions corresponding to the extension of the path of an eventuality as $S_{ext(path(e))}$, $M_{ext(path(e))}$ and $G_{ext(path(e))}$ we will abbreviate these expression by *source*(e), *mid*(e) and *goal*(e) (remember that *start*(e) and *end*(e) refer to the start and end *points* of the path corresponding to an eventuality, so we have *start*$(e) \in$ *source*(e) and *end*$(e) \in$ *goal*(e)).

A path p with extension x and a path q with extension y are *equivalent*, written $p \equiv q$ iff $S_x = S_y$ and $M_x = M_y$ and $G_x = G_y$.

We can change the analysis of "suivre" (*follow* with the object being a person) from Section 2.2, repeated below as *suivre*$_1$, which used a single event with subject and object, to a two event analysis (I will gloss over the temporal restrictions) with subject and object moving along equivalent paths.

$$\begin{array}{rll}
\textit{suivre}_1 & (np\backslash s)/np & \lambda y_{\textit{person}} \lambda x_{\textit{person}} \exists e.\textit{travel}(e,x) \wedge \textit{travel}(e,y) \\
\textit{suivre}_2 & (np\backslash s)/np & \lambda y_{\textit{person}} \lambda x_{\textit{person}} \exists e_1 \exists e_2.\textit{travel}(e_1,x) \wedge \textit{travel}(e_2,y) \wedge \\
 & & \qquad\qquad\qquad\qquad \textit{path}(e_1) \equiv \textit{path}(e_2) \\
\textit{longer} & (np\backslash s)/np & \lambda p_{\textit{path}} \lambda x_{\textit{person}} \exists e.\textit{travel}(e,x) \wedge \textit{path}(e) \equiv q \wedge q \subseteq p
\end{array}$$

In addition, as shown above, this definition gives us a simple way to treat a verb like "longer" (*to walk along* + np) which requires as its object something which can at least be coerced to a path in the context (typical examples in our corpus are rivers and valleys) and has as its truth conditions that the path followed is at least path-equivalent to a subpath of the path specified by the object argument.

4.3. *Verb Semantics*

With this in place, the three basic motion verb classes of Asher and Sablayrolles (1995) can be reconstructed as follows (refer back to Figure 5, though note that the figure displays the weaker semantics for medial prepositions: for the verb semantics, unlike the preposition semantics, M_x shares a frontier with R_M).

$$
\begin{aligned}
\textit{initial\_verb}(e, R_S) =_{\textit{def}} &\quad \text{TPP}(\textit{source}(e), R_S) \wedge \textit{mid}(e) \cup \textit{goal}(e) \subseteq {R_S}^{\mathsf{C}} \\
\textit{medial\_verb}(e, R_M) =_{\textit{def}} &\quad \text{TPP}(\textit{mid}(e), R_M) \wedge dc(R_M \cap \textit{mid}(e)^{\mathsf{C}}) \wedge \\
&\qquad\quad \textit{source}(e) \cup \textit{goal}(e) \subseteq {R_M}^{\mathsf{C}} \\
\textit{medial\_pp}(e, R_M) =_{\textit{def}} &\quad \text{PO}(\textit{mid}(e), R_M) \wedge dc(R_M \cap \textit{mid}(e)^{\mathsf{C}}) \wedge \\
&\qquad\quad \textit{source}(e) \cup \textit{goal}(e) \subseteq {R_M}^{\mathsf{C}} \\
\textit{final\_verb}(e, R_G) =_{\textit{def}} &\quad \text{TPP}(\textit{goal}(e), R_G) \wedge \textit{source}(e) \cup \textit{mid}(e) \subseteq {R_G}^{\mathsf{C}}
\end{aligned}
$$

Initial verbs give a region R containing the initial region S_x ($= \textit{source}(e)$) of the path, with the moving object moving to the complement (i.e. outside) of this region. Examples of initial verbs are “partir de” (*leave from*) and “sortir de” (*exit*). Final verbs follow the opposite pattern, starting outside of the region argument and ending inside it. Examples include “arriver à” (*arrive at*) and “atteindre” (*reach*).

The medial verbs are a bit more complicated (and their analysis diverges from Asher and Sablayrolles, 1995). To satisfy the semantics of a medial verb, such as “traverser” (*cross*), it does not suffice for the middle of the path to merely be a (tangential) part of the region R: the path must split the region into two parts. Together with an appropriate choice of S_x and G_x this gives, for our current purposes, an accurate enough semantics of medial verbs. Note that there is a difference in the treatment of medial verbs and of medial prepositions (such as “par” (*by*)): for medial prepositions the TPP relation is replaced by the PO relation, since “going from x to z passing by y” does not require x and y or y and z to be connected. Figure 5 displays the preposition semantics.

With all these abbreviations and definitions in place, the actual semantic recipes for motion verbs and spatial prepositions become very simple, as shown below (note the use of the interior operator):

$$
\begin{array}{rll}
\textit{sortir de}\ \text{loc} & (np\backslash s)/np & \lambda r \lambda x \lambda e.\textit{travel}(e, x) \ \wedge\ \textit{initial\_verb}(e, \mathrm{I}r) \\
\textit{par}\ \text{loc} & (s\backslash_1 s)/np & \lambda r \lambda s \lambda e(s\ e) \wedge \textit{medial\_pp}(e, \mathrm{I}r)
\end{array}
$$

5. Temporal Semantics

The temporal order of events forms an important part of reconstructing the itinerary. One readily available source of information for the relative order of events is verb tense. However, verb tense provides only rather weak truth conditions: from a sequence of sentences in the present tense, or a sequence in the *passé composé*, or a sequence in the *imparfait* we can conclude essentially nothing about the relative order of the eventualities in the discourse units.

Additional constraints on temporal order are imposed by verbal aspect and by the discourse relations between sentences (such as those of Asher and Lascarides, 2003). However, these are much harder to obtain algorithmically, at least in the context of wide-coverage semantics: they generally require world knowledge to be successfully applied (though work has been done on deriving these relations automatically, for example see Baldridge and Lascarides, 2005). So, while some frequent movement verbs, such as "partir" (*leave*) and "arriver" (*arrive*) are prototypical examples of punctual eventualities (*Achievements* in the terminology of Vendler), aspectual information is hard to exploit in practice.

In spite of this, connectives such as "puis" (*then*), "après que/après INF" (*after*) and "lorsque/en VPpres" (*while*) provide some reliable cues about the temporal ordering of discourse units which is easily exploited.

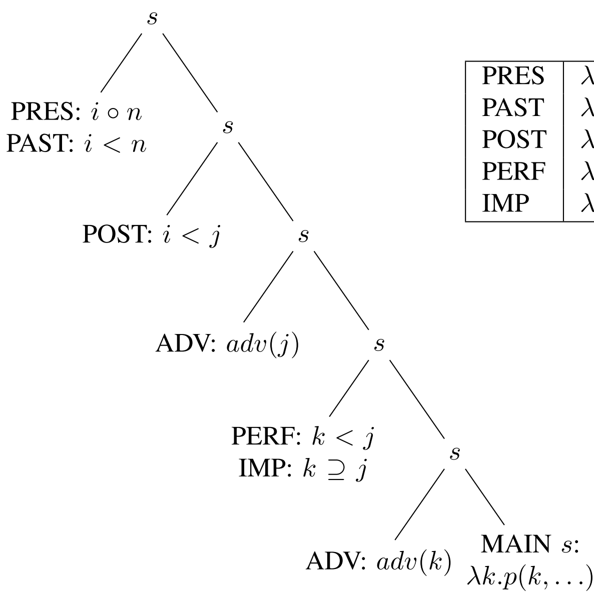
We will use an interval-based temporal semantics, assuming time is rightward branching; in other words, though there can be multiple futures, there is only a single past. Each individual branch of this "temporal tree" is treated as $\mathbb{R}$ (with some canonical conversion to the usual units of calendar days, hours, minutes, ...). Though this means that intervals can be incomparable in the temporal ordering, each temporal interval $\langle i, j]$ nonetheless has a "representative" or counterpart on all timelines which we obtain by "forgetting" on which branch we are.

Rightward branching gives a natural account of the progressive: we can say that the progressive inflection takes an event as input and returns a (proper) initial part of this event, while allowing the end point of the event to be incomparable with the speech point n. Similarly, though future events are clearly after the speech point n, different future eventualities are possibly incomparable.

For the temporal semantics of verbs, each eventuality is assigned a temporal interval. The transitive closure of the temporal relations between eventualities are computed using Allen's interval calculus (Allen, 1983) adapted to right-branching time (Reich, 1994).

In addition to the Allen relations (and right-branching extensions), our temporal primitives include a measuring function μ which measures the duration of temporal intervals (in minutes, hours, days as indicated by a subscript). A defined distance function δ measures the distance between two intervals i and j as the duration of the interval which touches the "ends" of both i and j; if $i < j$ then $\delta_M(i, j) = x$ iff $\exists i'.imi', i'mj$ [8] and $\mu_M(i') = x$. If $i > j$ the distance is $-\delta_M(j, i)$. If i and j share a point, then their distance is 0. If i and j are incomparable (i.e. they are in distinct futures: they neither share a point nor is there an interval i' which connects both), their distance is undefined.

8. m is Allen's "meet" relation, often written $\supset\!\subset$ in the literature.



PRES	$\lambda\phi\exists i.(\phi\ i) \wedge i \circ n$
PAST	$\lambda\phi\exists i.(\phi\ i) \wedge i < n$
POST	$\lambda\phi\lambda i\exists j.(\phi\ j) \wedge i < j$
PERF	$\lambda\phi\lambda j\exists k.(\phi\ k) \wedge k < j$
IMP	$\lambda\phi\lambda j\exists k.(\phi\ k) \wedge k \supseteq j$

Figure 6. *Verkuyl's compositional treatment of tense and adverbs*

5.1. *Tense*

For tense, we use the compositional treatment of Verkuyl (2008) (though using the binary relations between intervals of Verkuyl, 2001), summarized in Figure 6.

As shown in the figure, the main sentence is assigned a predicate p with several arguments, one of which is the variable k which stands for an eventuality (though Verkuyl, who does not adopt the Davidsonian line of the current paper, speaks simply of *indices*). In the main event nucleus, this variable is bound by a lambda abstraction, making the event nucleus of type $i \to t$. Successive application of the terms corresponding to the tense information and adverbs (Verkuyl allows temporal adverbs to modify the eventuality j introduced by the perfect to treat ambiguity, all other adverbs modify the variable k of the main eventuality).

5.2. *Temporal Adverbs and Prepositions*

Figure 7 shows the lexical meaning of some current lexical adverb patterns. n' corresponds roughly to Reichenbach's reference time R in past tenses and to the utterance time S in present tenses in Verkuyl's temporal semantics.

lorsque	$(s/s)/s$	$\lambda s_1 \lambda s_2 \lambda e \exists e'.(s_1\ e') \wedge (s_2\ e) \wedge \mathit{time}(e) \circ \mathit{time}(e')$
puis	$(s\backslash s)/s$	$\lambda s_2 \lambda s_1 \lambda e \exists e'.(s_1\ e') \wedge (s_2\ e) \wedge \mathit{time}(e') < \mathit{time}(e)$
vendredi	$s\backslash_1 s$	$\lambda s \lambda e.(s\ e) \wedge \mathit{time}(e) \subseteq \mathit{vendredi}$
à I	$s\backslash_1 s$	$\lambda s \lambda e.(s\ e) \wedge \mathit{time}(e) \circ I$
en X D	$s\backslash_1 s$	$\lambda s \lambda e.(s\ e) \wedge \mu_D(\mathit{time}(e)) \subseteq X$
pendant X D	$s\backslash_1 s$	$\lambda s \lambda e.(s\ e) \wedge \mu_D(\mathit{time}(e)) = X$
dans X D	$s\backslash_1 s$	$\lambda s \lambda e.(s\ e) \wedge \delta_D(n', \mathit{time}(e)) = X$
il y a X D	$s\backslash_1 s$	$\lambda s \lambda e.(s\ e) \wedge \delta_D(\mathit{time}(e), n') = X$
depuis X D	$s\backslash_1 s$	$\lambda s \lambda e.(s\ e) \wedge \delta_D(\mathit{time}(e), n') = X \wedge \mathit{time}(e) \circ n'$
depuis I	$s\backslash_1 s$	$\lambda s \lambda e.(s\ e) \wedge \mathit{time}(e) \circ i \wedge \mathit{time}(e) \circ n'$

Figure 7. *Temporal prepositions and adverbs; D is a* duration*, I is an* interval

6. Inference

The spatial component and the temporal component of the logic, together with the lexical semantics, give a basic set of relations between discourse elements. The natural question to ask here is: given a set of these basic relations (temporal or spatial) which new relations can we infer?

The picture which would be most pleasing for the logician in this respect is to have a theorem prover (the parser) provide the lambda term, which upon normalization produces a logical formula, with inference of further properties being done by another dedicated theorem prover. The wrinkle in this picture is that the complexity of the logics starts at NP-complete (for the RCC8 case) and quickly becomes undecidable (for an overview of the complexity of spatial logics with connectedness and for the undecidability of $S4_u$ with connectedness in Euclidian space, see Kontchakov *et al.*, 2008; Nenov, 2011).

Two basic options are open here: first, in spite of the computational complexity, many theorem provers work well enough to justify their inclusion in complex reasoning tasks, as shown, for example by Bos and Markert (2005). The second option, maybe less satisfying to the logician but considerably more efficient, is the use of precomputed transitivity tables which allow us to infer new relations on the basis of old ones. Allen (1983) is a classic example of this approach. RCC8 and several of its extensions have such composition tables as well, though we leave finding a transitivity table for (an interesting fragment of) $S4_u c$ as an open question here.

7. Putting It All Together: the System in Action

Now that we have seen all the different elements of the system, let us look at the results for a small example from the corpus.

$x_0\ y_0$
nommé$(x_0,$ **Gavarnie**$)$
lieu(x_0)
nommé$(y_0,$ **pas_des_Echelles**$)$
lieu(y_0)
magnifique(y_0)

$y_1\ e_1$
d$($**start**$(e_1), x_0) <$ **d**$($**end**$(e_1), x_0)$
PO$($**mid**$(e_1), y_0)$
dc$($**complement**$($**mid**$(e_1))) \cap y_0)$
à_cheval(e_1)
orateur(y_1)
travel(e_1, y_1)
[e_2 | **temps**$(e_1) <$ **temps**(e_2) ; **temps**$(e_2) \circ$ **maintenant**]
temps$(e_1) \subseteq$ **soir**

Figure 8. *Output for Example (5)*

(5) Le soir, je suis allé à cheval par le magnifique pas des Echelles vers Gavarnie.
In the evening, I went on horseback to Gavarnie passing through the magnificent Echelles mountain pass.

Figure 8 shows the (slightly simplified) Grail output for the example sentence. According to the treatment of presupposition we are following, presuppositions appear in their own DRS to the left of the main DRS, as is the case for "Gavarnie" and "pas des Echelles" (both toponyms; in general, proper names are presupposed).

The main DRS on the right has the spatial information in the first three conditions: the semantics of "vers" (*towards*) is on the first line and (part of) the semantics of "par + LOC" (*by*) is on the second and third line. The temporal information is in the embedded DRS towards the bottom and on the final line. The embedded DRS introduces a second eventuality variable e_2 (which is not accessible in the main DRS) which overlaps with "maintenant" (*now*) and which is completely after the main eventuality e_1 (this is the semantics of the present perfect, combining PRES and PERF, the two conditions together imply that e_1 takes place completely before the time of speech/writing. In addition, the time of the eventuality is included in the constant "soir" (*evening*, kept as a constant since we feel that in the 18:00-23:59 interval gives an inappropriate sense of precision).

8. Conclusions and Future Work

We have described the main components of a computational system providing a semantics for itineraries: POS-tagger, Named Entity Recognition, supertagger, parser and the specific implementation of spatio-temporal semantics.

An important missing part is the evaluation of the semantics produced. It is hard to compare an output DRT with a prior gold standard and the construction of semantically annotated corpus (such as Basile *et al.*, 2012) was not feasible within the temporal constraints posed by Itipy project. Though the system works well in practice, a more systematic comparison of the itineraries produced automatically with itineraries assigned by human readers is a vital next step.

Some parts of the current implementation are still missing, most notably a component for anaphora resolution. Though DRT has been developed with some anaphoric puzzles in mind, in practice the number of potential discourse referents in a DRS is rather big, even for small texts, and the selection of the appropriate antecedent is not easy. We think we could benefit from some of the lessons from the NLP community and implement a type of hybrid NLP/DRS anaphora resolution system.

Other extensions include a treatment of nominalisations (e.g. "arrivée", *arrival*, in the context of itineraries) and definite descriptions (e.g. "le sommet", *the summit*, which provides a very precise location if we can find the correct mountain being referred to) and the inclusion of discourse structure briefly alluded to in the text.

On a more general note, we are very interested in seeing how far we can increase the level of detail of wide-coverage semantics as it is used here. There are two main strategies for doing so (though they are by no means exclusive):

– we give an algorithm for computing more detailed information; this implies we already have a fairly good idea of what is going on, what the relevant elements are and how to combine them effectively. The treatment of tense is an example of this method;

– on the basis of a sufficient amount of annotated data (which includes easily obtained features which can reasonably be thought to help decide between the distinct categories), we train a tagger: this is essentially the approach taken for Named Entity Recognition (though its combination with semantics can be seen as a sort of hybrid approach).

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