A Compositional Semantics for Directional Modifiers

— Locative Case Reopened —

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1. Abstract

This paper presents a model–theoretic semantics for directional modifiers in English. The semantic theory presupposed for the analysis is that of Montague Grammar (cf. Montague 1970, 1973) which makes it possible to develop a strongly compositional treatment of directional modifiers. Such a treatment has significant computational advantages over case–based treatments of directional modifiers that are advocated in the AI literature.
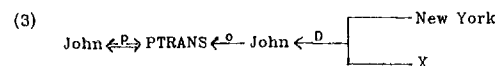
2. Case–based Treatments

Among natural language processing systems which attempt to incorporate spatial information, the following strategy seems to prevail. Directional or locative modifiers are treated either as corresponding to slots in *case frames* in the canonical lexical representations of verbs (cf. Celce 1972, Hendrix, Thompson and Slocum 1973), or as corresponding to *conceptual cases* in the (meta–linguistic) conceptualization of actions (Schank 1975).

Case based approaches to the semantics of directional modifiers can be characterized as *weakly compositional* in the following sense: In a verb phrase such as *fly to Chicago* the prepositional phrase contributes semantically the meaning of the NP *Chicago* as the directional or locative goal of the action associated with the verb phrase. However, the directional preposition *to* itself does not make a semantic contribution at all to the meaning of the verb phrase as a whole. Instead, *to* merely serves as a syntactic marker for a semantic entity, namely a locative or directional case whose meaning cannot be separated from, but rather is an integral part of a given verb frame or conceptual structure. By contrast, the semantics of directional modifiers that I will be advocating in this paper is *strongly compositional* in the sense that directional prepositions serve as autonomous syntactic and semantic units. Consequently, each word in a phrase such as *fly to Chicago* contributes its own, independent meaning to the meaning of the phrase as a whole.

This strongly compositional analysis of directional modifiers has a number of crucial computational advantages over case–based approaches. Consider how inferences between sentences such as (1) and (2) can be handled by the two types of approaches.

(1) John went to New York.
(2) John was in New York.

In Schank (1975, p.53) sentence (1) corresponds to the conceptual structure in (3).

(3)

$$\text{John} \xleftarrow{P} \text{PTRANS} \xleftarrow{o} \text{John} \xleftarrow{D} \begin{cases} \text{New York} \\ \text{X} \end{cases}$$

(3) be should read as: "John is at some time in the past (p) engaged in an act of physical transfer (PTRANS) whose object (o) is John and whose direction (D) is from some location X to New York." The fact that (1) implies (2) is expressed by attaching to the bi–directional arrow in (3) the structure in (4). (cf. Schank 1975, p. 54)

(4)

$$\text{John} \xleftrightarrow{\quad} \text{LOC(N.Y.)} \quad \uparrow r$$
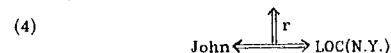
Schank calls the *r–link* (r for result) between structures (3) and (4) an *inference*. However, the term *inference* is really a misnomer because the association between structures such as (3) and (4) is merely a matter of stipulation but does not follow from any general principles or axioms that would constrain the language of conceptual structures. For that matter, there is nothing in Schank's system that prevents a link between (3) and a structure which expresses that John does not reach the location *New York*. In the analysis we will develop below, on the other hand, the inference between (1) and (2) follows logically from the semantics of motion verbs such as *go* in conjunction with the semantics of directional modifiers.

Consider next the issue of how easy or difficult it is to upscale natural language systems whose treatment of directional modifiers is case–based. Assume a case–based system in which only those verbal frames or conceptual structures are implemented that relate locative or directional case to verbs of motion. Now imagine that we want to extend coverage to verbs such as *wave* which, as illustrated in (5), allow directional modifiers such as *to*.

(5) The President waved to the reporters.

Since *wave*, unlike verbs of motion, does not entail a change of location for the agent involved, a new verbal frame or conceptual structure would have to be introduced into a system which only covers motion verbs. Moreover, locative or directional case would have to be reintroduced into the system as well because in a case–based system the specific effect of a given semantic case has to be determined for each individual frame or conceptual structure. This is a direct consequence of the weakly compositional semantics of such systems and in turn leads to an highly redundant method of upscaling. Since my analysis of directional modifiers is, by contrast, strongly compositional, upscaling becomes much easier. In the case of extending coverage to a verb like *wave*, all that needs to be added is the lexical semantics for the verb itself, while the semantics of directional modifiers can remain untouched.

Finally, consider how a case–based approach to directional modifiers fares with respect to phrases such as the ones given in (6).

(6) From Russia with Love
To New York and then to Atlanta

Since in case–based systems locative or directional case is a relational notion and is crucially dependent on a verbal frame or conceptual structure, it becomes impossible to assign an interpretation to verbless phrases as in (6). One strategy for extending case–based systems to such verbless phrases would consist in supplementing the relational notion of directional or locative case by a non–relational counterpart which does not depend on some verbal frame or conceptual structure. But the resulting account of locative or directional case would once again be highly redundant since essentially all of the cases in the system would have to be split into a relational and a non-relational version.

2. Motion Verbs as Location Predicates

In their literal sense, locative use *to* and *toward* typically modify motion verbs such as *walk, run, drive, slither, move* etc. An adequate treatment of the directional modifiers themselves is, therefore, closely connected to a semantic account of such motion verbs. In Hinrichs (1985) I argue that motion verbs should be treated as *stage level predicates* in the sense of Carlson (1977), namely as predicates whose arguments refer to stages of individuals. Stages are connected to individuals in Carlson's ontology by a realization relation R, which associates a given individual with all of the (spatio–temporal) stages at which that individual is present.

Motion verbs such as *move* can be understood as prototypical examples of stage-level predicates, since such verbs predicate something about the spatio–temporal location of one or more objects. Following Hinrichs (1985), I interpret *move* in terms of a three-place stage level predicate $move^+$, whose first two argument positions range over individual stages realizing the referents of the object and subject NPs, respectively. Following Davidson (1977), the rightmost argument position ranges over events, or more specifically over event

stages which realize the event that the referents of the subject and object NPs are engaged in. Thus, $move^+(x^S)(y^S)(e^S)$ should be read as: "the referents of x^S and y^S are engaged in an event stage e^S realizing an event of moving." As is customary in Montague Grammar, I express constraints on lexical meaning in terms of meaning postulates that constrain the set of possible models of semantic interpretation.[1] The meaning postulate in (7) states that an event stage e^S which realizes a moving event spatio-temporally includes (symbolized as $\leq$) at least the location of the referent denoted by the object argument, i.e. $y^S \leq e^S$. This does not exclude the possibility that the location of the referent of the subject NP can be contained in the event stage as well, but this is not required for *move*, as (8) shows.

(7) $\forall\ x^S, y^S, e^S\ [\ move^+(x^S)(y^S)(e^S) \rightarrow y^S \leq e^S]$
(8) John moved the troops.

Of course, different motion verbs will have different properties with respect to how the locations of the event stages relate to the stages that realize the individuals involved in these event stages. Consider verbs like *slither*, *walk*, and *run* which in my framework are analyzed as two-place stage level predicates. For these predicates the location of the event stage is equal to the location of the agent, i.e. the referent of the subject NP. This can be enforced by a meaning postulate as in (9).

(9) $\forall\ x^S, e^S\ [\delta^+(x^S)(e^S) \rightarrow x^S = e^S\ ]$, where δ translates
slither, walk, run, etc..

The lexical entailment associated with the verb *move* to the effect that the location of the referent of the object NP changes can be captured by the meaning postulate in (10). (The symbols $<$ and $\neq_s$ used in (10) stand for temporal precedence and spatial inequality, respectively.)

(10) $\forall\ e^S, x_1^S, y^S, x^o\ [R(x_1^S, x^o)\ \&\ move^+(x_1^S)(y_1^S)(e_1^S) \rightarrow \exists\ x_2^S$
$[R(x_2^S, x^o)\ \&\ x_1^S\ <\ x_2^S\ \&\ x_1^S \neq_s x_2^S]$

3. The Semantics of *to* and *toward*

Now I let a *to*-phrase, as a modifier of untensed verb phrases (IV*), operate semantically on the event stages in the denotation of the unmodified verb phrase in such way that the event stages in the denotation of the resulting IV* phrase constitute a spatio-temporal path (in the sense of Cresswell 1978) between some specified point of origin to the location of the term combining with *to*. The translation of *to* is given in (11).

(11) *to* translates as $\lambda P \lambda P \lambda l_1 \lambda x^i P\ [\lambda y^i \exists l_2 [R(l_2, y^i)\ \&$
$PATH(l_1, l_r, l_2)\ \&\ P(x^i)(l_1)]]$

The formula following the lambda abstractions in (11) introduces an individual stage l_2 realizing an individual object y^i, which is the one bound by the noun phrase (NP) combining with *to* to form the IV* modifier. The second conjunct in the formula asserts that the denotation of the event stage located at l_1, which is to be bound by the translation of the IV* phrase that the *to*-phrase combines with, qualifies as a *spatio-temporal path* (a notion formally defined in Hinrichs 1985) between some point of origin l_r and the spatio-temporal location of the point of destination. Finally, the third conjunct asserts the truth of the unmodified IV* phrase that the *to*-phrase combines with. It is this last conjunct that automatically guarantees the inference from sentences such as (12) to sentences such as (13).

(12) Fangs slithered to the rock.
(13) Fangs slithered.

Using the translation for *to* suggested in (11), sentence (12) receives the reduced translation in (14) according to my analysis.

(14) $\exists e^S, e^i\ [R(e^S, e^i)\ \&\ PAST(e^S)\ \&\ \exists x^S\ [R(x^S, f)\ \&\ \exists x^o \forall z^o\ [$
$rock'(z^o)\ \&\ \exists z^S\ [R(z^S, z^o)\ \&\ slither'(x^S)(e^S)\ \&$
$PATH(e^S, l_r, z^S)] \leftrightarrow x^o = z^o]]$

Paraphrasing (14), it says that there is an event stage realizing some individual event of Fangs' slithering such that that event stage lies in the past and the spatio-temporal location of the event stage constitutes a path between some implicit point of reference l_r and the location of some unique rock object. The point of reference l_r occurs as a free variable in the formula in (14); l_r is to be understood as an indexical parameter similar to the notion of a *reference point* proposed by Reichenbach (1947) for the interpretation of tenses in English.

Notice that the notion of a path in the translation of *to* in (11) and hence also in the translation for (12) given in (14) is defined to hold of the process making up a particular event. Moreover, due to the postulate in (9), the referent of the subject NP, when it combines with a motion verb such as *slither to the rock*, is realized by a stage spatio-temporally co-extensive with the path denoted by the *to* phrase. This fact guarantees the inference between sentences such as (12) and (15).

(15) Fangs was at the rock.

For other classes of verbs the same type of inference, namely identifying the path with the position(s) of the referent of the subject NP, cannot be drawn. For sentences such as (16) we do not want to claim that the stages realizing John make up a path to Boston. Rather it is the object NP, in this case an event term, that constitutes the path. The same is true of (17); it is the ball whose locations constitute a path to the location specified in the *to*-phrase.

(16) John made a phone call to Boston.
(17) Carol set the ball to Lucy.

Let us now turn to the treatment of the preposition *toward* whose lexical translation rule is given in (18).

(18) *toward* translates as $\lambda P \lambda P \lambda e^S \lambda x^i P(\lambda y^i\ \exists l\ [R(l, y^i)\ \&\ \exists l'$
$[PATH(l', l_r, l))\ \&\ e^S \leq l'\ \&\ l_r\ <\ e^S\ \&\ P(x^i)(e^S)]])$

The translation for *toward* constrains the value of the event stage variable e^S in such a way that e^S has to be spatio-temporally contained in some initial segment of a path l' from some implicit point of origin l_r to the location l of the referent of the NP with which *toward*. The requirement that the value of e^S has to be an initial segment of such a path follows from the condition that the implicit point of origin l_r has to be properly contained in e^S. *Proper* containment is necessary in order to avoid that the value of e^S could be equal to the point of origin, in which case an object could count as moving toward another object if the spatial location of the first object remains unchanged.

Using (18), sentence (19) is translated as in (20).

(19) Fangs slithered toward the rock.
(20) $\exists e^S, e^i\ [R(e^S, e^i)\ \&\ PAST(e^S)\ \&\ \exists x^S\ [R(x^S, f)\ \&\ \exists x^o [\forall z^o$
$[rock'(z^o) \leftrightarrow x^o = z^o]\ \&\ \exists z^S\ [R(z^S, z^o)\ \&\ slither'(x^S, e^S)$
$\&\ \exists l\ [PATH(l, l_r, z^S)\ \&\ e^S \leq l\ \&\ l_r\ <\ e^S]]]]]$

The translation in (20) says that there is an event stage realizing some individual event of Fangs' slithering such that that event stage lies in the past and the spatio-temporal location of the event stage constitutes the initial part of a path between some implicit point of reference l_r and the location of some unique rock object. Since e^S in (20) is an initial part of a complete path to the rock, the truth of a sentence such as (12) entails the truth of (19), but not vice versa. Moreover, (12), but not (19), entails (15).

4. The Aspectual Effect of *to* and *toward*

Apart from supporting the relevant inference patterns between sentences such as (12), (15) and (19), an adequate analysis of *to* and *toward* should also account for a systematic difference in

the aspectual behavior of these two directional modifiers. Sentences such as (21a) which involve the preposition *to* to describe *atelic events* or, in the terminology of Vendler (1967), *activities*. Sentences such as (21b), on the other hand, refer to telic events or to *accomplishments* in Vendler's classification.

(21) a. John walked to the library.
     b. John walked toward the library.

These aspectual properties can be demonstrated by examining the cooccurrence restrictions of the sentences in (21) with temporal modifiers such as *in an hour* as in (22) and with *for an hour* as in (23).

(22) a. John walked to the library in an hour.
     b. * John walked toward the library in an hour.
(23) a. John walked to the library for an hour.
     b. John walked toward the library for an hour.

As first pointed out by Vendler, only telic events or accomplishments can occur with temporal modifiers such as *in an hour*. Modifiers such as *for an hour* can occur with both activities and accomplishments. However, when modified by temporal *for*, only activities as in (23a) can be interpreted as describing a single event. If temporal *for* occurs with sentences that describe accomplishments as in (23b), such sentences have to be interpreted in some special fashion to make them semantically acceptable. (23b), for example, can best be understood as referring to an iterative event, namely of John's repeatedly walking to the library during the period of one hour.

Since doing something *for* x amount of time means doing something during most if not all subintervals of the interval x, sentences such as (24), which refer to atelic events or activities, can be characterized as being *temporally homogeneous*.

(24) Fangs slithered toward the rock.

To do something *in* x amount of time, on the other hand, means to do something at some unique interval within x. Since telic events or accomplishments can be modified by temporal *in*, they, in contrast to activities or atelic events, can be described as being *temporally heterogeneous*: telic events such as (25) come about over the course of some unique time interval I', i.e. not at some subinterval of I' or at some interval properly containing I'.

(25) Fangs slithered to the rock.

If my analysis of directional *toward* and *to* is an adequate one, it should predict that verb phrases formed with directional *toward* refer to temporally homogeneous events, while verb phrases formed with *to* refer to temporally heterogenous events. Due to the way in which I have defined *toward* as an initial subpart of a path to the projected point of destination, the reference property of temporal homogeneity associated with *toward* can, in fact, be reconstructed in the following way. Let us assume that there is a location l_1 which qualifies as an initial segment of a path from a putative point of origin r_1 to a destination d. Moreover, let us assume that r_2, the temporally final bound of l_1, is in turn the temporally initial bound for a location l_2 which forms the intial part of a path from r_2 to d. Then it follows that $l_1 + l_2$, the spatio-temporal sum of l_1 and l_2, is also an initial segment of a path from r_1 to d. This is precisely what is required to make the semantics of *toward* homogeneous.

Since my account of motion verbs and directional *toward* does predict that sentences such as (26) correspond to atelic and semantically homogeneous events, my analysis can support inferences from sentences such as (26) to sentences such as (27).

(26) United Flight 342 has moved toward Logan Airport
     for the last fifteen minutes.
(27) United Flight 342 moved toward Logan Airport ten
     minutes ago.

Inference patterns between sentences such as (26) and (27) are, in fact, highly relevant for data base interface systems that process spatial information. Imagine that sentence (26) is presented to a database that monitors plane movements. If the system does not have the capability to infer that the event described in (26) is true at any subinterval of the fifteen

minutes mentioned in (26), the United flight in question would erroneously not be counted when the answer to a subsequent query such as (28) is computed.

(28) How many planes moved toward Logan Airport ten
     minutes ago?

If we compare the semantics of *toward* with the semantics of *to* as defined in (11), it turns out that *to* is heterogeneous in its reference in the same way as accomplishments. Recall that the semantics of *to* is defined in terms of a complete path between a point of origin and a point of destination. Since for any given path there do not exist any sublocations within that path that themselves would qualify as a path between the same two locations, the heterogeneous reference property of *to* follows automatically.

5. Conclusion

In order to make an even stronger case in favor of my analysis of directional modifiers, I would have to demonstrate how it can be generalized to locative prepositions other than *to* and *toward*. Even though I cannot discuss this issue in detail in the present paper, I should like to point out in conclusion that the notion of a PATH plays an important role in the treatment of other directional prepositions such as *between*, *along* and *across*. In the case of *across* the path seems to be bounded by two locations on the peripherie of the referent of the NP *across* is combined with; i.e. *across the meadow* specifies some path extending from one end of the meadow to the other. Notice, however, that the two locations that mark the two endpoints of such a path cannot be chosen arbitrarily but in some sense have to be "opposite each other". Undoubtedly, various pragmatic considerations enter the picture if one wants to make this requirement of *oppositeness* formally more precise. Thus, it appears that the notion of a path has to be complemented by additional constraints, if one wants to account for semantically more complex prepositions such as *across*. Even though I will have to leave the formulation of such additional constraints to future research, it should be obvious from these brief remarks that the notion of a path is a central notion for the semantics of directional modifiers in general.

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