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) \[ \text{John} @ \text{New York} \text{PTRANS}\rightarrow \text{John} \rightarrow \text{X} \]

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 destination (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) \[ \text{John} \rightarrow \text{LOC}(\text{NY}) \]

Schank calls the r-link (r for resultant) 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 (6), 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, sit, 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 a motion verb like 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(t₂)(y₃)(x₂) should be read as: "the referents of x₂ and y₃ are engaged in an event stage e₅ realizing an event of moving." As 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 e₅ which realizes a moving event spatio-temporally includes (symbolized as ☐) at least the location of the referent denoted by the object argument, i.e., y₃ ≤ e₅. 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) y ≡ x₁, y₃ ≤ e₅ [move(t₂)(y₃)(x₂) → y₃ ≤ e₅]
(8) John moved the troops.

Of course, different notion 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. Comb, 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 (6).

(9) y ≡ x₁, e₅ [comb(t₁)(y₃)(x₂) → y₃ = e₅], where δ translates either, walk, run, etc., respectively.

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 < l₁ and ≡ used in (10) stand for temporal precedence and spatial inequality, respectively.)

(10) y ≡ x₁, x₂, y₃, z° [comb(t₁)(y₃)(x₂) & move(t₂)(y₃)(x₂) → 3 x₂
[comb(t₁)(x₂)(y₃) & move(t₂)(y₃)(x₂)]

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 a 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 λP (P), x₂, F [y₃ | R(l₂, y₃) & PATH(l₁, l₁, l₂) & P(x₂)(l₁)]

The formula following the lambda abstractions in (11) introduces an individual stage l₁ realizing an individual object y₃, 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 l₁, 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 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.

¹All the meaning postulates appearing in this paper are formulated in the language of extensional logic developed in Hinrichs (1985).
the aspectual behavior of these two directional modifiers. Sentences such as (26a) which involve the proposition to describe atelic events or, in the terminology of Vendler (1967), activities. Sentences such as (26b), 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 (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 telic event. If it is temporal for occurs with a support 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.

(25) Fangs slithered toward 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 l1 which qualifies as an initial segment of a path from a putative point of origin r to a destination d. Moreover, let us assume that l2, the temporally final bound of l2, is in turn the temporally initial bound for a location l2 which forms the initial part of a path from r2 to d. Then it follows that l1-l2, the spatio-temporal sum of l1 and l2, is also an initial segment of a path from r to d. This is precisely what is required to make the semantics of toward homogeneous.

Since my account of notion verbs and directional toward does predict that sentences such as (26) correspond to telic and semantically homogeneous events and 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 database 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 (29) 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 such 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 periphery 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.

6. List of References

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